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AN EXPERIMENTAL INVESTIGATION ON THE EFFECT OF SUBSONIC INLET MACH NUMBER ON THE PERFORMANCE OF CONICAL DIFFUSERS

by

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The work reported herein formed the basis of an MS thesis in Mechanical Engineering at Purdue University.

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NOMENCLATURE

A	Area
AR	Area ratio = (outlet area)/(inlet area)
C_{PR}	Performance = $(P_2-P_1)/q_1$
C_{PR_i}	Ideal performance = $(P_2-P_1)_i/q_1$
M	Mach Number
N	Diffuser length along centerline
P	Static pressure
q	Mean dynamic pressure = $\frac{1}{2}\rho U^2$
R	Diffuser radius
U	Free stream velocity
u	Velocity at any point
W	Diffuser width - two-dimensional, plane-walled
X	Distance along centerline from diffuser inlet
δ^*	Displacement thickness of boundary layer
η	Effectiveness = $(P_2-P_1)/(P_2-P_1)_i$
θ	Momentum thickness of boundary layer
ρ	Density
2ϕ	Total divergence angle

Subscripts

i	Ideal
0	Stagnation
1	Diffuser inlet plane
2	Diffuser outlet plane

ABSTRACT

Experiments have been performed to determine the effect of subsonic inlet Mach number on diffuser performance and flow regimes for a wide range of conical diffuser geometries.

For incompressible flow the line of first appreciable stall, line a-a, is essentially that found by McDonald and Fox (Reference 2). As the Mach number is increased, the flow tends more toward separation in all cases.

Diffuser performance maps are presented for three different inlet Mach numbers (M_1 = 0.25, 0.55, 0.70). There is no significant variation in the location of the line of maximum performance at constant length to inlet radius ratio, line α-α, with inlet Mach number. For M_1 = 0.25 line α-α of the present study is virtually identical to that found in the earlier water flow studies of McDonald and Fox (Reference 2).

INTRODUCTION

Performance of conical diffusers is dependent on both flow and geometric variables. Previous work has indicated that the geometric variables of importance are total divergence angle, 2ϕ, length to inlet radius ratio, N/R_1, and area ratio, AR. The flow variables are more numerous and often somewhat more difficult to identify. In part they are inlet boundary layer thickness, Mach number, turbulence intensity, and Reynolds number. The large number of variables makes a generalized theory of diffusers difficult; considerable data are required to determine the effect of a single variables over a range of the other variables.

In the past many investigators have been more interested in improving the performance of a single diffuser rather than formulating any relationships for a wide range of geometries and flow conditions. A summary of previous investigations of two-dimensional, plane-walled diffusers is given by Kline, et al[1*] for the case of steady, incompressible flow with a thin inlet boundary layer (compared to the inlet width of the diffuser). The summary includes observations of flow regime (degree of separation) and measurements of performance over a wide range of diffuser divergence angles and length ratios.

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* Superscript numbers will be used to denote items in the List of References.

The results showed that flow regime was primarily dependent on the geometry of the diffuser, but that the performance depended on other variables as well. The results of Reference 1 were presented on coordinates of divergence angle versus length ratio. The location of "first appreciable stall" was designated as lina a-a; the line of maximum pressure recovery for fixed N/W_1 was designated as line α-α. The location of these lines for two-dimensional, plane-walled diffusers is shown in Figure 1. McDonald and Fox[2] performed a systematic investigation of flow regimes and diffuser performance over a wide range of conical diffuser geometries. The location of lines a-a and α-α as presented in Reference 2 are also shown in Figure 1. Both of these studies were for incompressible flow and were primarily concerned with the effect of geometric variables on flow regimes and diffuser performance.

The purpose of this work is to extend the investigations of McDonald to regions of compressible flow; i.e., to determine the effect of subsonic inlet Mach number on flow regime and performance in conical diffusers. Several investigators (Ackeret[3]; Copp[4]; Little and Wilbur[5]; Naumann[6]; Scherrer and Anderson[7]) have taken data on the effects of Mach number on diffuser performance; however, these data are only for a small number of geometries grouped around the line of optimum performance; the values of the geometrical parameters employed in these earlier investigations are shown in Figure 1. It should be noted that in all cases the exit of the diffusers was joined to a tailpipe. This limited data indicated that

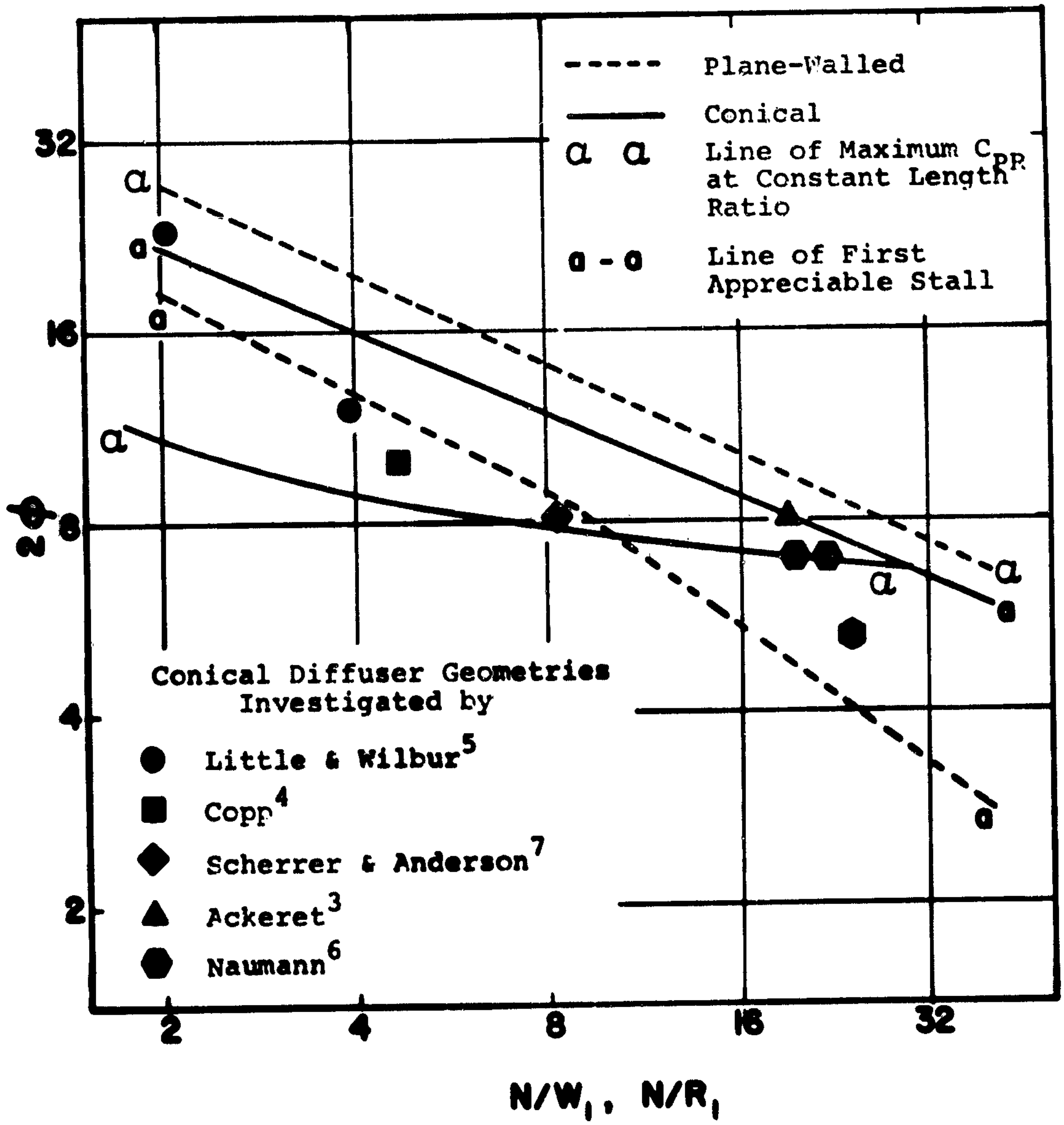

Figure 1. Lines of First Appreciable Stall and Lines of Maximum C_{PR} at Constant Length Ratio for Conical and Plane-Walled Diffusers (Taken from Reference 2)

there is little effect of Mach number on diffuser performance or flow regime until the flow becomes choked. In view of the limited data available, a systematic investigation was undertaken to determine the effect of subsonic inlet Mach number on diffuser performance and flow regime over a wide range of conical diffuser geometries.

In the present study the dependence of flow regime and performance on inlet Mach number was determined experimentally for the nineteen conical diffuser geometries employed in the work of McDonald and Fox[2]. The results were then correlated with the geometric variables in an attempt to find useful relationships for predicting diffuser behavior under a given set of inlet conditions.

EXPERIMENTAL FACILITY

The arrangement and dimensions of the wind tunnel used in the present study are shown in Figure 2. The tunnel was of the blow through type. Air from a Spencer turbo-blower came through a 24 inch diameter pipe and into a transition section; the transition section changed the passage from the round pipe to a 20 inch x 20 inch square channel which served as an upstream plenum. This plenum section, containing flow straighteners and screens, was 32 inches in length. Flow entered the diffuser test sections through a converging nozzle designed according to Smith and Wang[8]. (The nozzle was designed from curve (a) of Reference 8; the nozzle contour was taken from a chart given by the authors and scaled up to the desired size.) The nozzle was bolted through the downstream face of the plenum and extended a distance of 7.86 inches upstream into the plenum. For ease of construction, the nozzle was fabricated in two pieces as shown in Figure 3. The constant area section extended for 5 inches beyond the plenum wall. The inside of the straight section was machined and polished to insure close matching with both the end of the nozzle and the diffuser. The diffuser was then bolted to the straight section with the alignment maintained by two pins. The exit of the diffuser was fastened to a plexiglass plate which was in turn bolted to

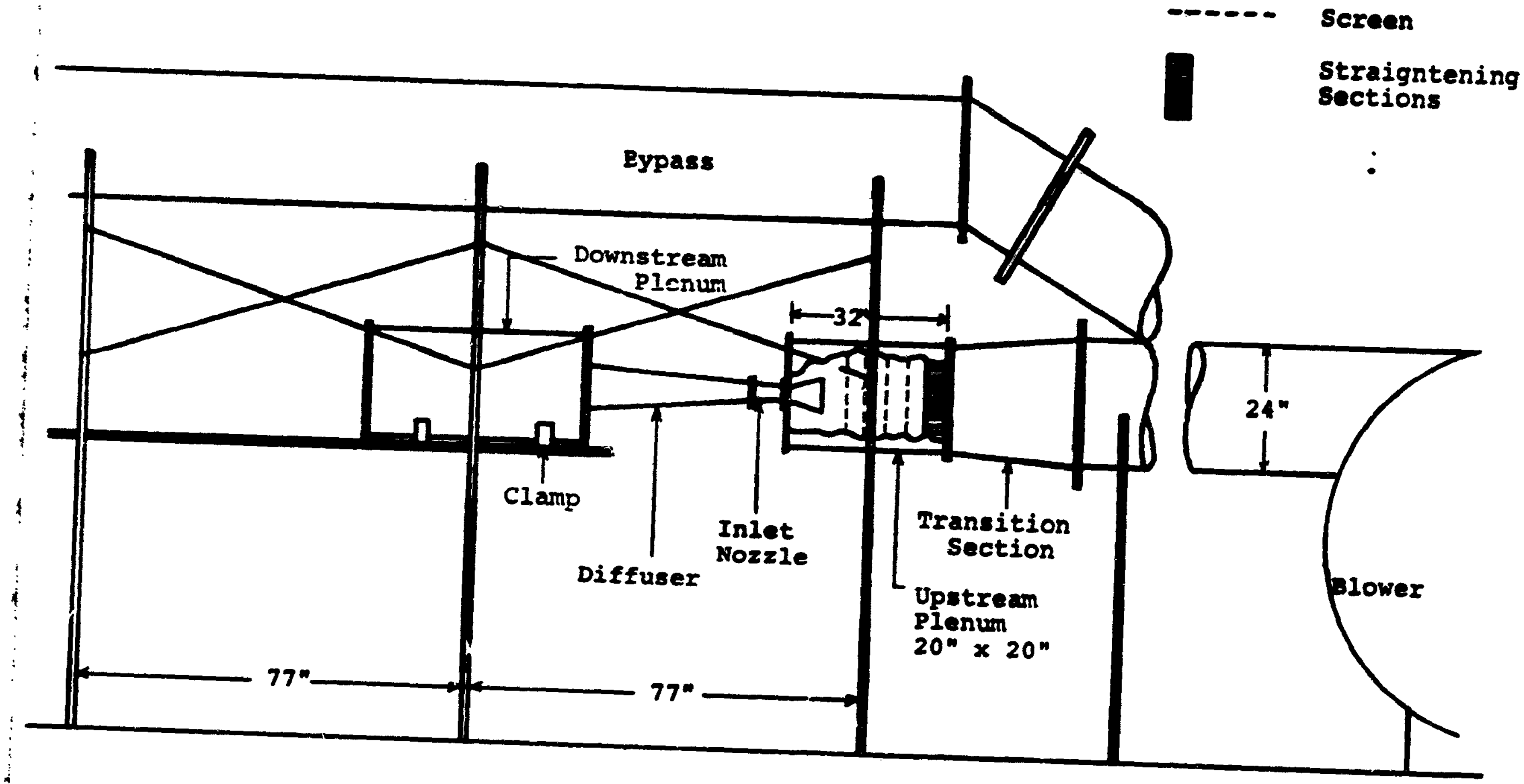

Figure 2. Experimental Facility

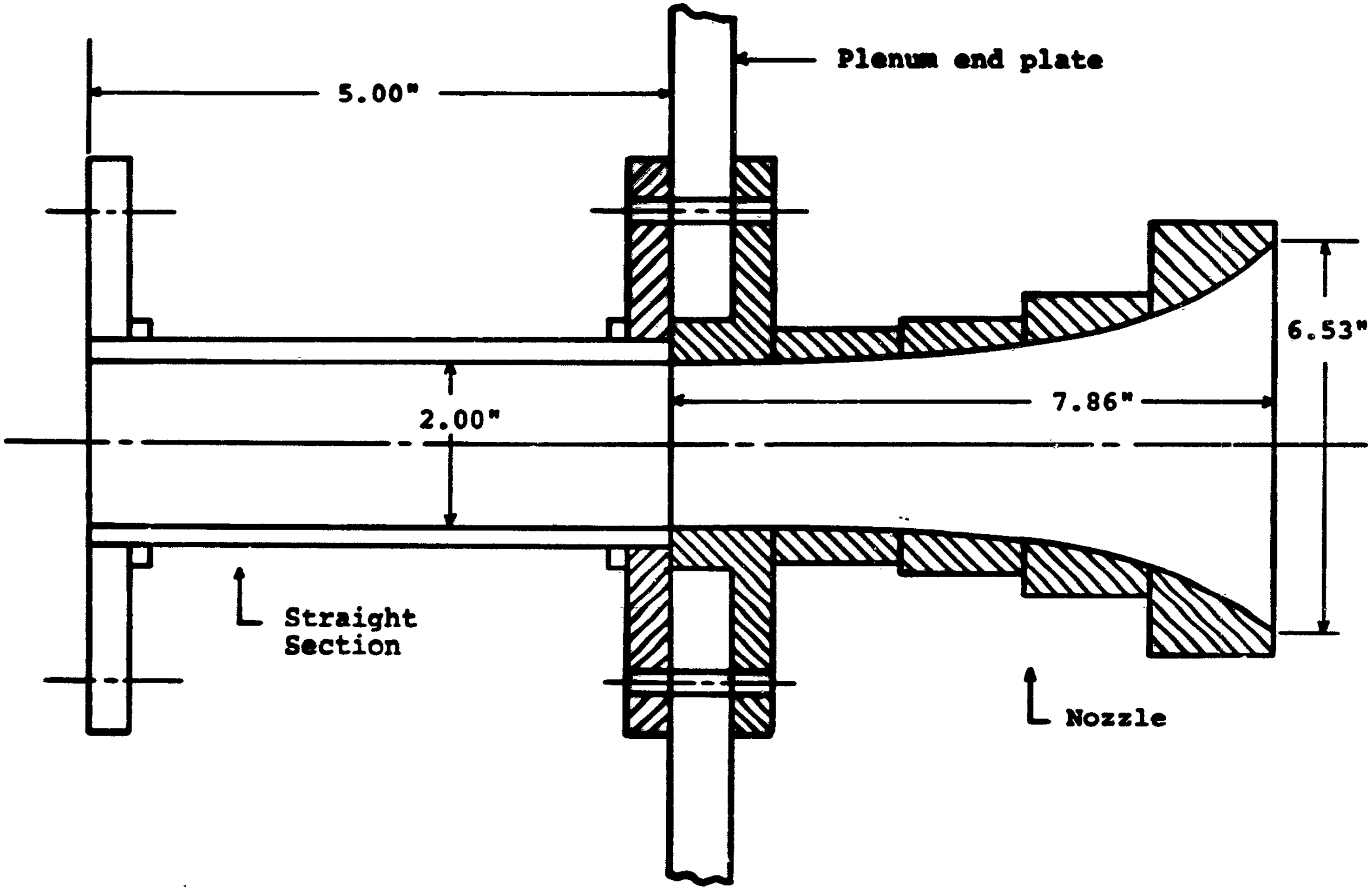

Figure 3. Inlet Nozzle

the downstream section of the tunnel. The attachment was made so that the exit plane of the diffuser was flush with the plate. The downstream part of the tunnel was clamped to the plywood sheet upon which it rested in such a manner that it could be moved back and forth to allow for different diffuser lengths. The downstream plenum was 42 inches long; the flow exhausted to the room.

Wall pressure measurements were taken along the diffuser length; the pressure tap locations are given in Appendix A. Tygon tubing was run from the pressure taps to a bank of mercury manometers. The manometers had a least count of 0.05 inches and this was used as the basic module of the readings taken. Since there was usually a fluctuation in the readings of the manometers of 0.025 inches, it was felt that it would be unrealistic to take readings closer than the least count.

During the early runs a great deal of trouble was encountered with separation and irregular flow in diffusers which should have run smoothly. This was traced to disturbances in the air at the exit of the blower. To correct this condition, a set of flow straighteners and 4 screens were installed in the upstream plenum. The straighteners consisted of a $1\frac{1}{2}$ inch square grid of sheet metal 4 inches long. This broke up the large disturbances and the screens following the straighteners further reduced the scale of the disturbances. Three other steps were also taken which helped even more than the straighteners and screens. The butterfly valve on the blower outlet, which was at first used to control the air flow, was left wide open; the air flow was controlled by a butterfly valve on the blower inlet. This eliminated the large vortex which was being shed off of the partially opened outlet valve. Through use of the bypass the blower power level was maintained above 150 kw. This put the blower above its surge point. Extraneous piping was removed from the blower inlet so that the blower inlet flow was reasonably uniform. With these precautions taken, the output of the blower became quite regular and at low speed the diffusers behaved as they had for McDonald and Fox[2].

The diffusers employed in the present work were those used by McDonald and Fox[2]. The range of divergence angles and length ratios cover a wide range of diffuser geometries including the region of maximum diffuser performance. A description of the diffuser design and construction can be found in Reference 2 (page 37.).

The degree of separation (flow regime) in the diffusers was determined by observations of cotton threads taped to the diffuser walls. Threads were equally spaced around the circumference of the diffuser at several axial positions along the diffuser length. Each of the threads was reinforced with a slight amount of glue on the free end. Without the glue the threads tended to ravel in the high velocity air stream. To obtain the maximum sensitivity, the amount of glue used was kept to an absolute minimum. The degree of separation was determined according to the criteria of Table 1. The cases where separation was localized in one part of the diffuser (such as the downstream end) are noted in the data presentation.

Table 1. Flow Regime Criteria

Movement and orientation of thread	Type of flow	Symbol
Thread held near wall, pointing downstream, occasionally wiggling	Steady flow with occasional disturbance	-
Major part of time thread points downstream, wiggling; random flickering (thread quickly points upstream, then downstream again) indicating temporary and local separation	Intermittent transitory stall	I
Thread whips continually upstream and downstream, indicating rapid and chaotic occurence and disappearance of separation	Local transitory stall	T
Thread whips upstream and downstream major part of time; thread held in upstream position wiggling at random intervals	Local transitory stall with intermittent fixed stall	TIF
Thread held upstream major part of time; temporary whipping at random intervals	Local fixed stall with intermittent transitory stall	FIT
Thread held upstream with end wiggling	Local fixed stall	F

RESULTS

The flow regime was determined in a given diffuser as a function of inlet Mach number. The flow regimes are indicated on Figure 4. The first symbol indicates the low speed flow regime; the second symbol indicates the flow regime at the highest inlet Mach number tested. The low speed results differed little from those of McDonald and Fox[2]. However, with increasing inlet Mach number the flow tended more toward separation in all cases. In instances where this does not show on Figure 4, it is because the worsening of the flow was not enough to push it into the next flow regime category. Another item worthy of note is that as length was added to the diffusers, the flow tended to worsen only in the added section. In other words, the flow in the first 4 inches of an 8 degree, 4 inch diffuser tended to be the same as the flow in the first 4 inches of an 8 degree, 8 inch diffuser.

To determine performance the data were taken for each diffuser as the Mach number was increased incrementally up to a maximum. For about half the diffusers this maximum was at the point of local choking and for the others it was at the limit of the blower. In either case, the maximum inlet Mach number was always greater than 0.65. Data were taken for at least 10 values of the Mach number between low speed flow and the limit points. The data taken were the plenum (stagnation) pressure, diffuser inlet static pressure (in the

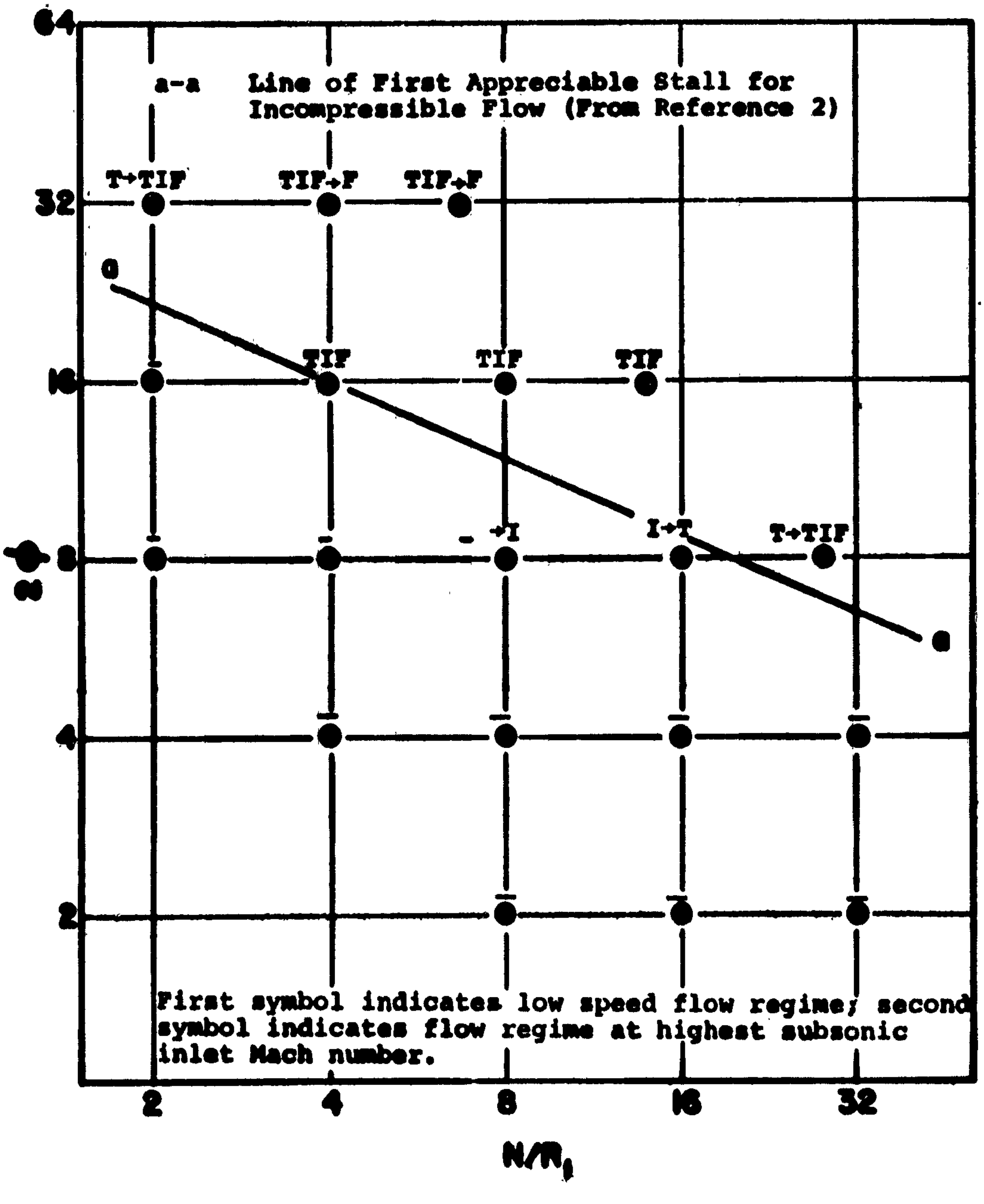

Figure 4. Effect of Inlet Mach Number on Flow Regimes in Conical Diffusers

constant area portion of the nozzle), the static pressures at stations along the diffusers and the downstream plenum pressure. From these the diffuser performance and the pressure profile along the diffuser could be obtained. All the data taken are summarized in Appendix A.

The tunnel system was checked to determine the inlet turbulence intensity and inlet boundary-layer thickness. A hot wire anemometer was used for both of these measurements. The equipment used was a constant current Flow Corporation model HWB 3. A single wire was mounted, calibrated and then used for all measurements. For an inlet free stream velocity of 160 fps the turbulence intensity was found to be at a rather high level of 10%. There was evidentally a high turbulence level created in the blower that was only partially corrected by the screens and large contraction ratio.

The velocity profile was integrated to give the momentum and displacement thicknesses. For an inlet free stream velocity of 160 fps the ratio of momentum thickness and displacement thickness to inlet radius were 0.011 and 0.017 respectively. The actual boundary layer thickness was on the order of 0.06 inches.

In calculating the performance from the pressure data the following assumptions were made:

1. Friction in the nozzle is negligible and the nozzle flow is one-dimensional. This is reasonable because of the short distance involved. Thus, the one-dimensional isentropic relations can be used to calculate the Mach number at the diffuser entrance.

2. Stagnation conditions occur in the upstream section of the wind tunnel. Calculations showed a better than 100:1 velocity ratio between the test section and the upstream plenum. Thus, the upstream air is essentially stagnant with respect to the test section.

3. The static pressure at the exit of the diffuser is the same as that read by a static pressure tap located in the plane of the diffuser exit and 6 inches from its centerline.

Diffuser performance as a function of inlet Mach number was originally plotted on nineteen separate graphs, one for each diffuser. In general, the performance showed little variation over the range of Mach numbers tested. Close to choking, however, there is sudden, sharp decrease in performance.* This is very similar to the results obtained by previous investigators. Any systematic variation of diffuser performance with inlet Mach number seemed to be dependent on the line of first appreciable stall. Below the line of first appreciable stall the smaller angle diffusers with relatively smooth flow exhibited a slight upward trend in performance as the inlet Mach number was increased. This trend was not present in the diffusers close to the first appreciable stall line; in diffusers close to the first appreciable stall line performance is essentially constant until choking is reached. Above the line of first appreciable stall, the performance decreased with increasing Mach number. In general as the location above the line increased, the drop off in performance, with increasing inlet Mach number, increased.

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* See Appendix D.

The separate performance curves were combined into sets for either constant area ratio, constant length ratio, or constant divergence angle. The results plotted for constant area ratio are presented in Figures 5-9. In Figure 5, all of the curves essentially fall on the same line. Examination of the flow regime chart shows that all three of the diffusers in the figure lie well inside the unseparated region. In Figure 6, all but one of the curves fall together. Examination of the flow regime chart shows that the diffuser with the lowest performance for all Mach numbers has a geometry which lies above the line of first appreciable stall. In Figure 7, the two geometries with the lower performance are located above the line of first appreciable stall; the diffuser showing the lowest performance lies at the greatest distance above the line. This same trend in diffuser performance is observed at increased area ratio as shown in Figures 8 and 9.

For a given area ratio, diffuser performance, at a given Mach number, is independent of diffuser angle (or length ratio) for diffuser geometries lying below the line of first appreciable stall. For a given area ratio, diffuser performance will drop off at all Mach numbers as one proceeds to geometries lying above line a-a. The drop off in performance increases with increasing distance above line a-a (increased flow separation). The consistancy of these results can be taken as further substantiation of the location of the line of first appreciable stall in conical diffusers as presented by McDonald and Fox[2].

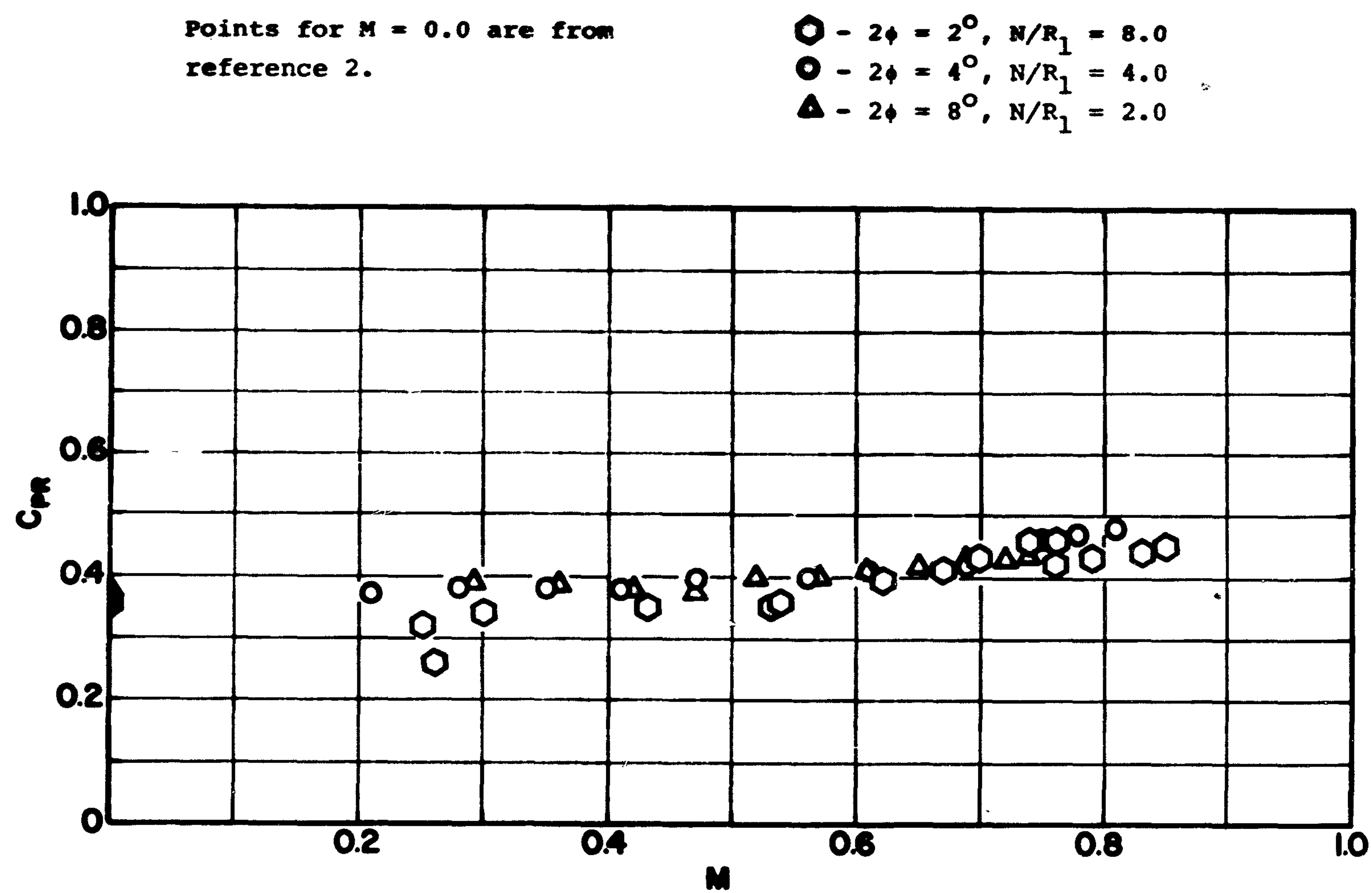

Figure 5. Diffuser Performance vs. Inlet Mach Number for AR = 1.30.

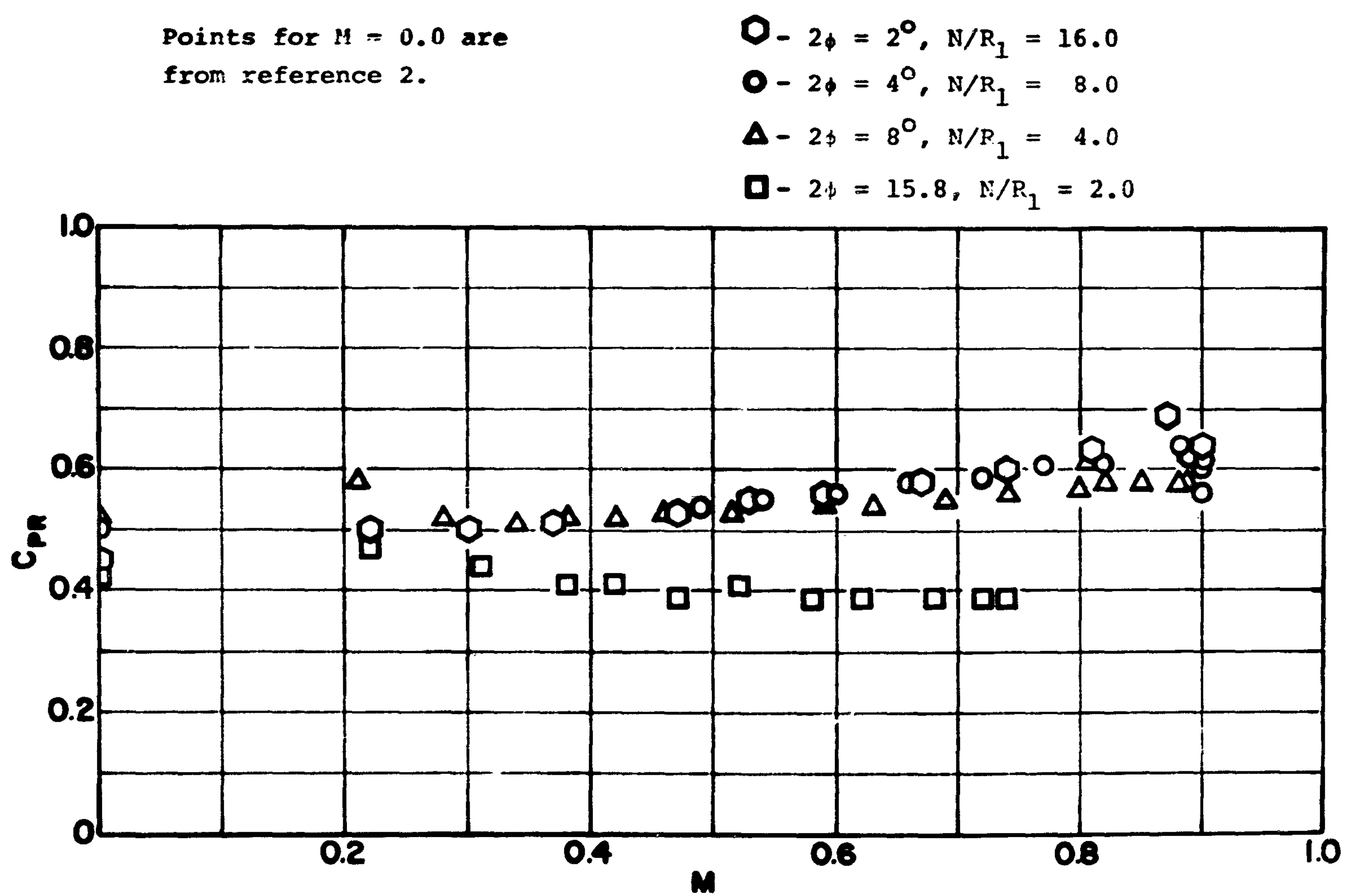

Figure 6. Diffuser Performance vs. Inlet Mach Number for AR = 1.64.

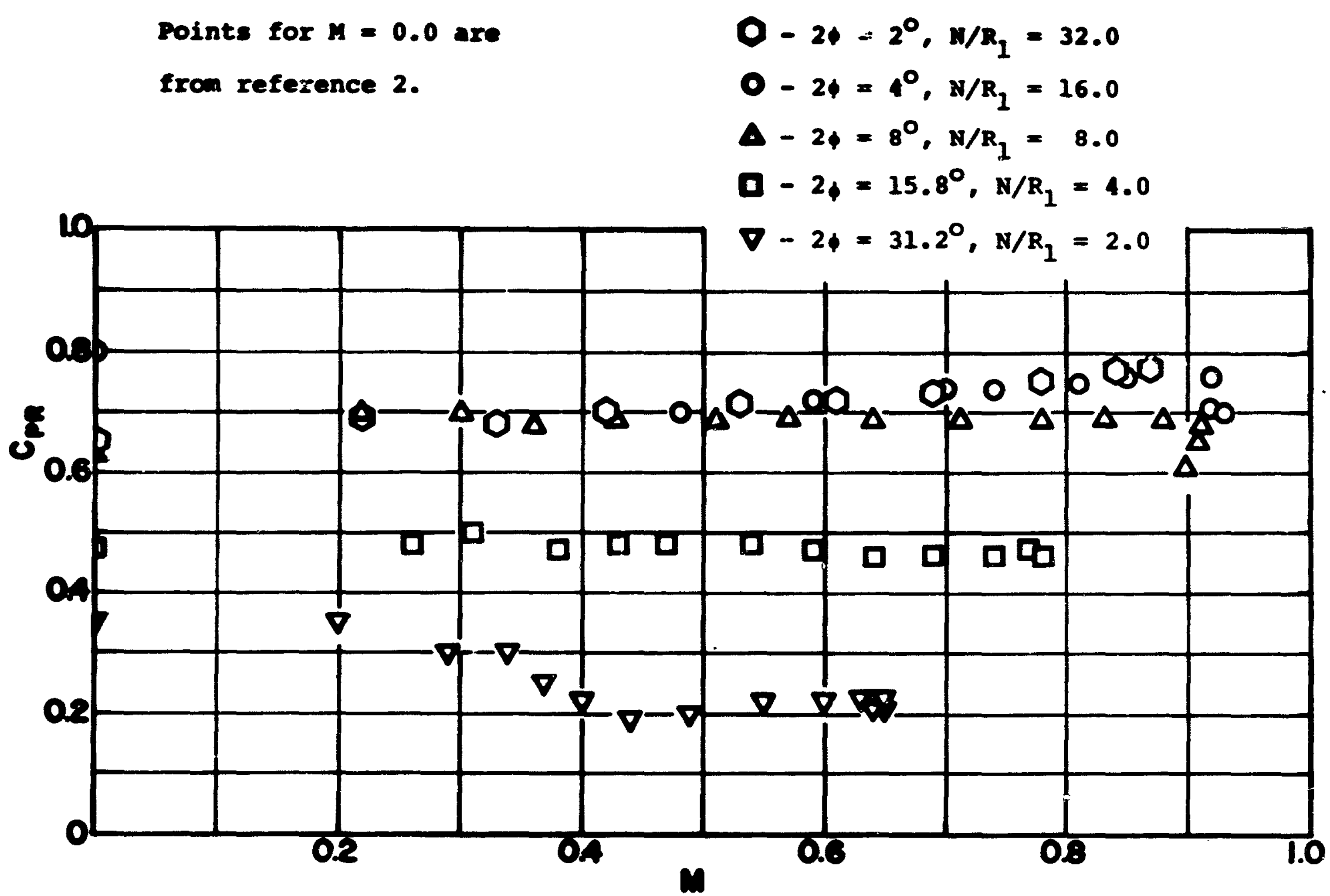

Figure 7. Diffuser Performance vs. Mach Number for AR = 2.43.

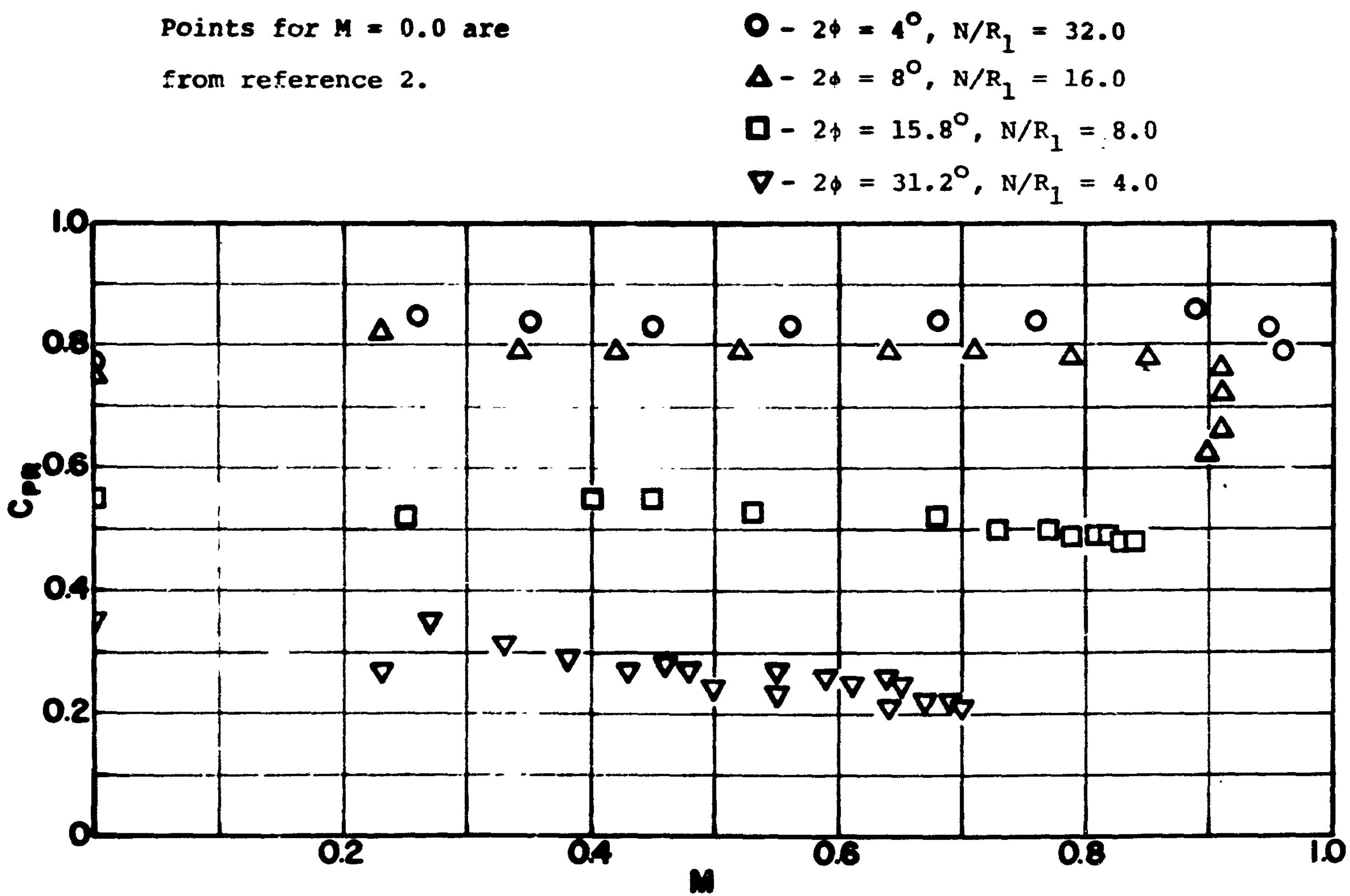

Figure 8. Diffuser Performance vs. Inlet Mach Number for AR = 4.48.

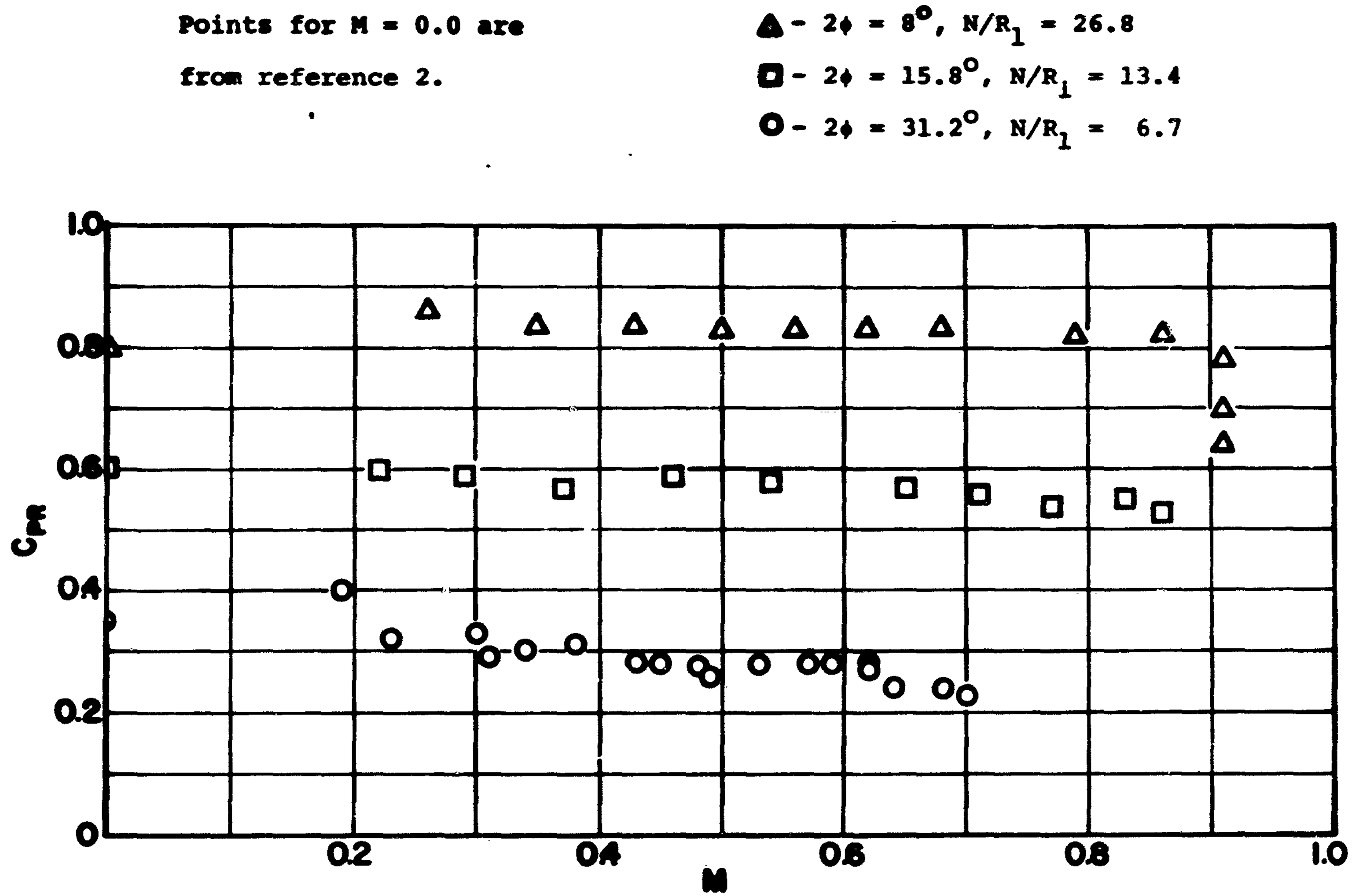

Figure 9. Diffuser Performance vs. Inlet Mach Number for AR = 8.27.

No systematic variation in diffuser performance as a function of Mach number was observed when the curves were plotted for constant length ratios. Consequently these plots are not reproduced here.

Figures 10-14 show diffuser performance versus inlet Mach number at constant divergence angle. On these plots the results are not as clear as those plotted for constant area ratio; however a systematic variation is evident. For a given divergence angle, the performance at any Mach number is a maximum for diffusers with the maximum area ratio. The spread of performance as a function of the area ratio for a given divergence angle decreases as the divergence angle is increased. At a divergence angle of 31.2 degrees, diffuser performance is uniformly low and essentially independent of area ratio at all Mach numbers.

Figures 15, 16, and 17 present performance maps for conical diffusers at Mach number of 0.25, 0.55 and 0.70 respectively. Lines of constant performance are presented on plots of area ratio versus length ratio. For a given value of M_1, these constant performance contours were obtained from three different cross plots of the data*; the data were plotted as C_{PR} vs N/R_1 at constant AR, C_{PR} vs AR at constant 2ϕ and C_{PR} vs 2ϕ at constant N/R_1. A summary of the data employed and the actual cross plots are given in Appendix B.

The location of the line of maximum performance at constant diffuser length to inlet radius ratio, line α-α is shown on each of the performance maps. On Figure 15 the dashed line shows the location of line α-α as determined in

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* See Appendix C.

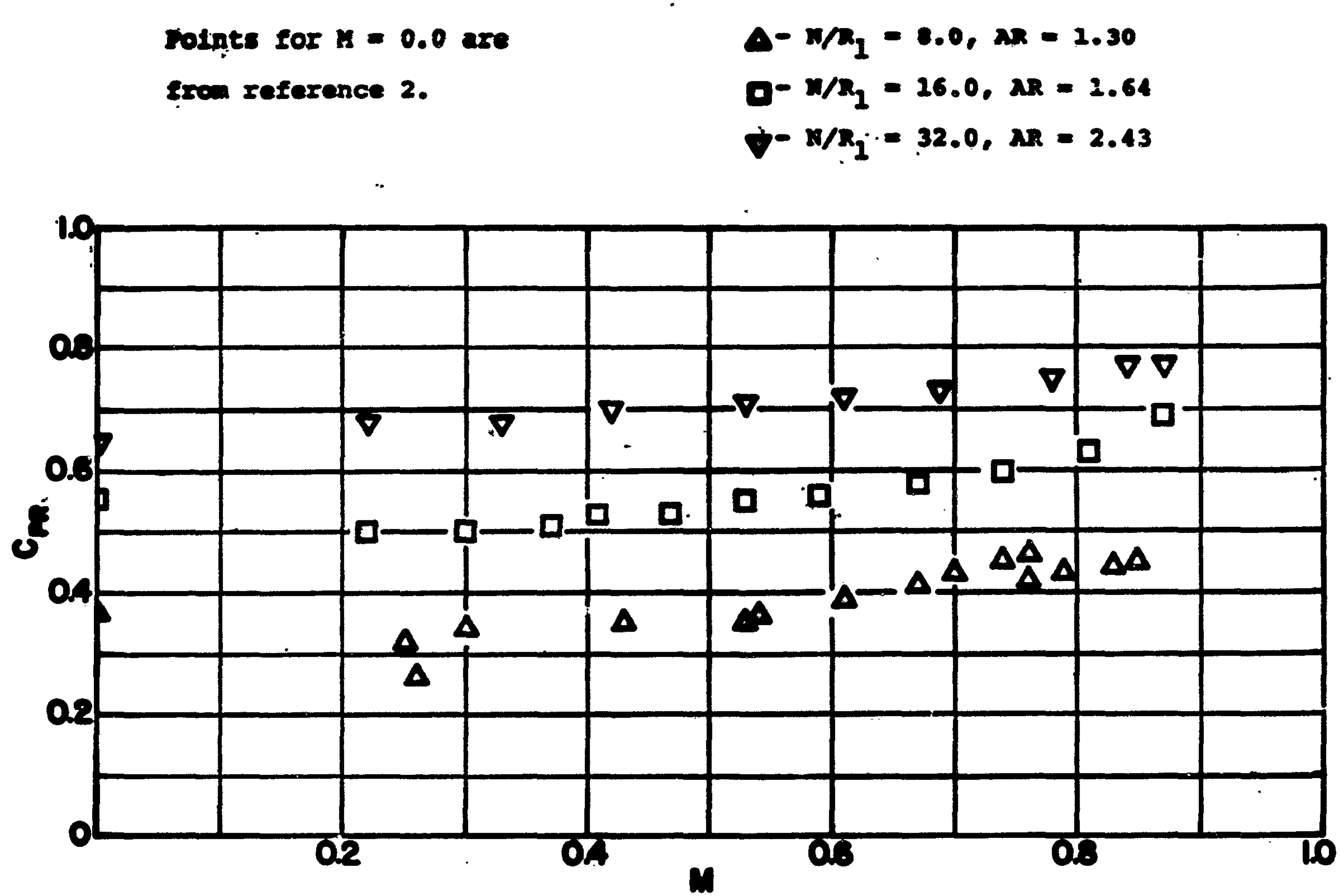

Figure 10. Diffuser Performance vs. Inlet Mach Number for $2\phi = 2^{o}$.

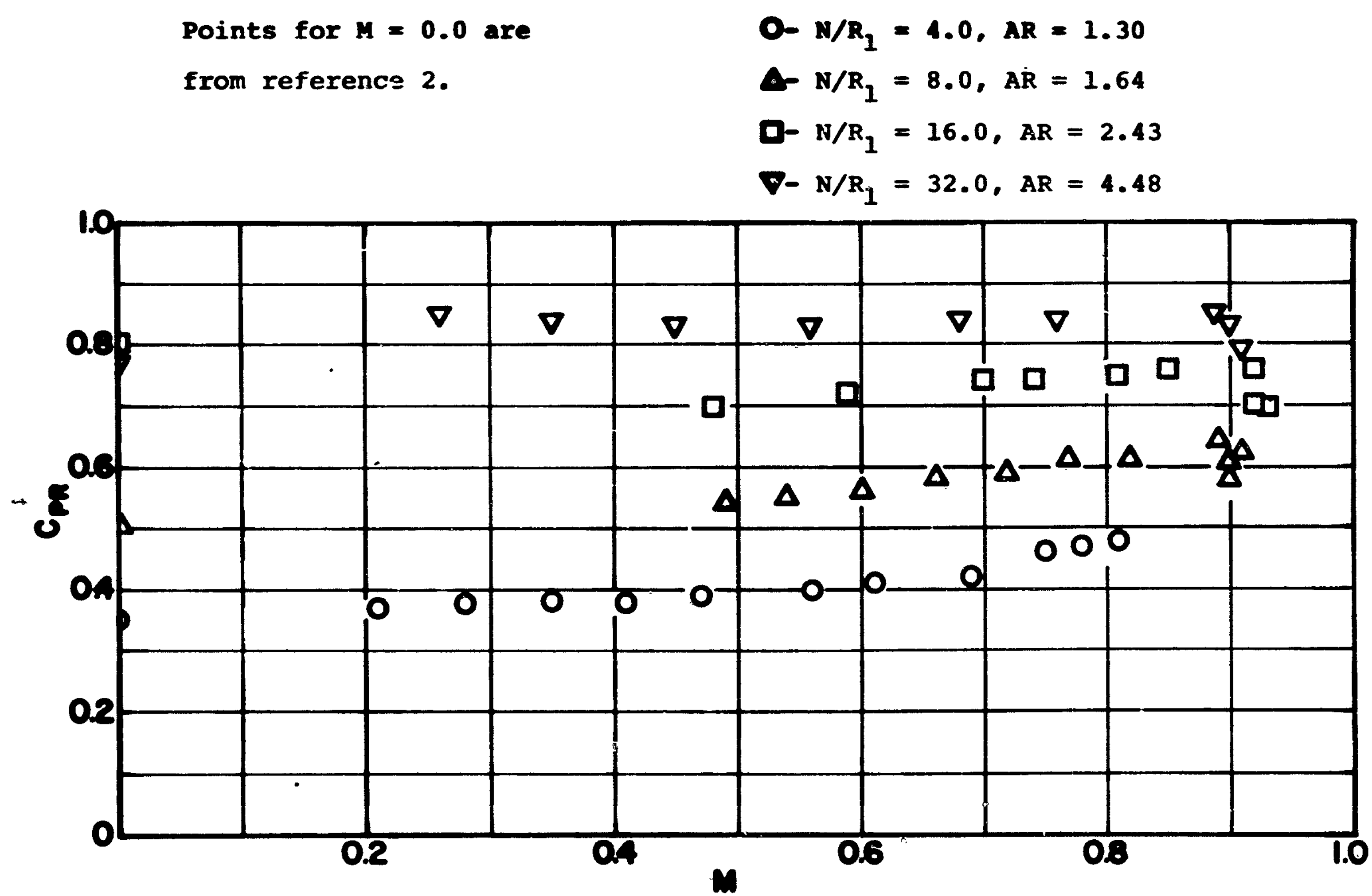

Figure 11. Diffuser Performance vs. Inlet Mach Number for $2\phi = 4^{\circ}$.

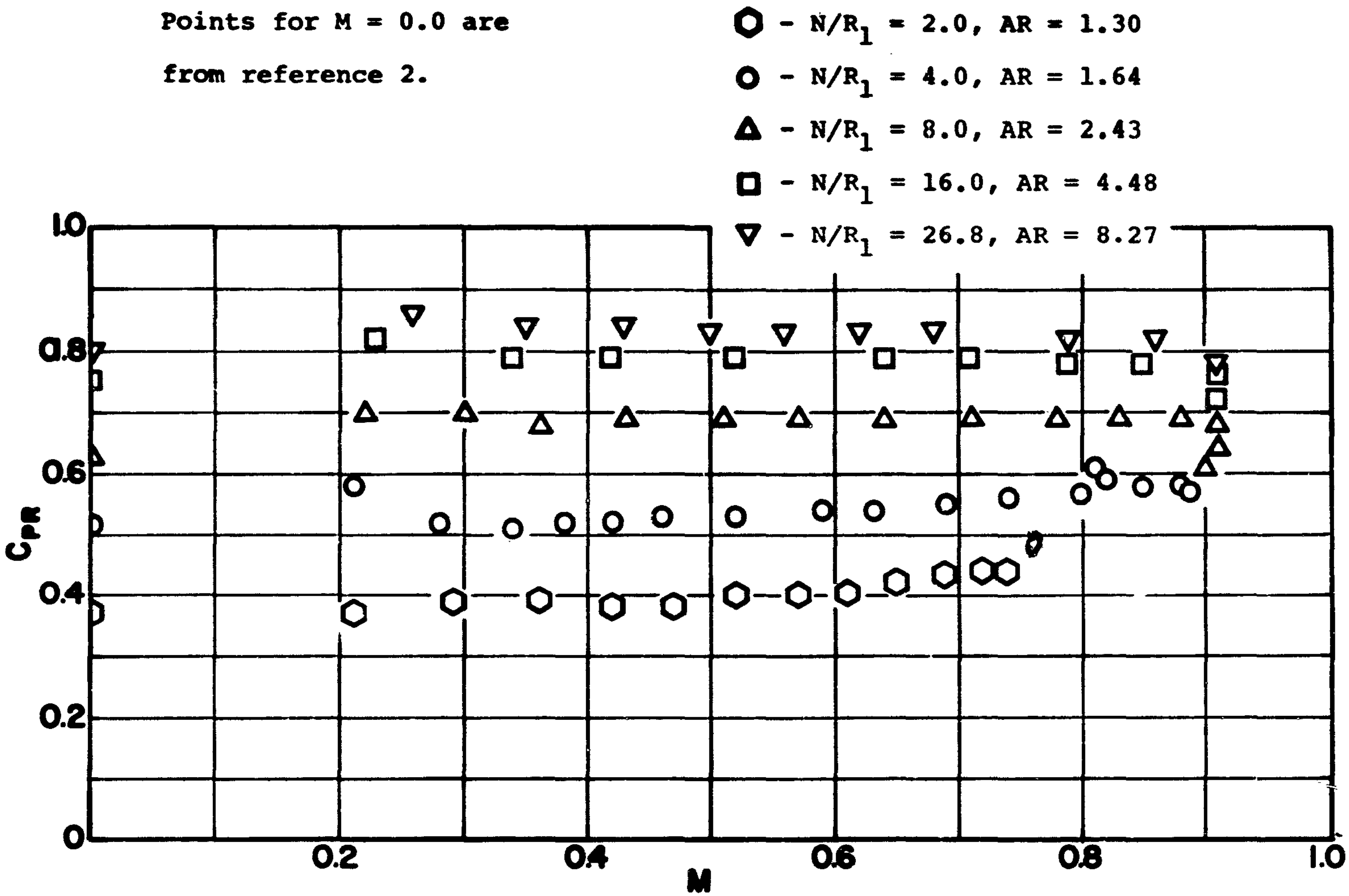

Figure 12. Diffuser Performance vs. Inlet Mach Number for $2\phi = 8^{o}$.

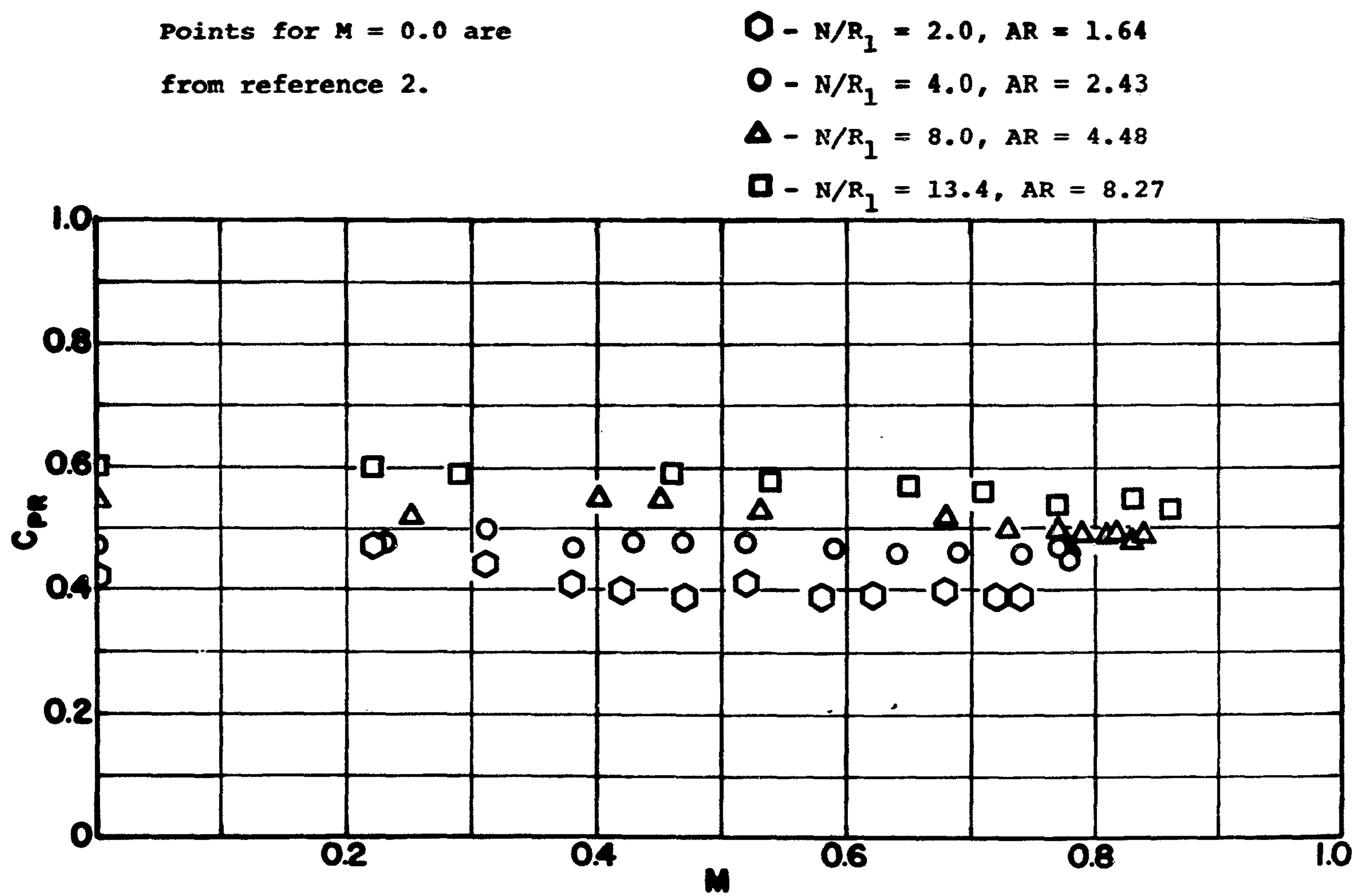

Figure 13. Diffuser Performance vs. Inlet Mach Number for $2\phi = 15.8^{o}$.

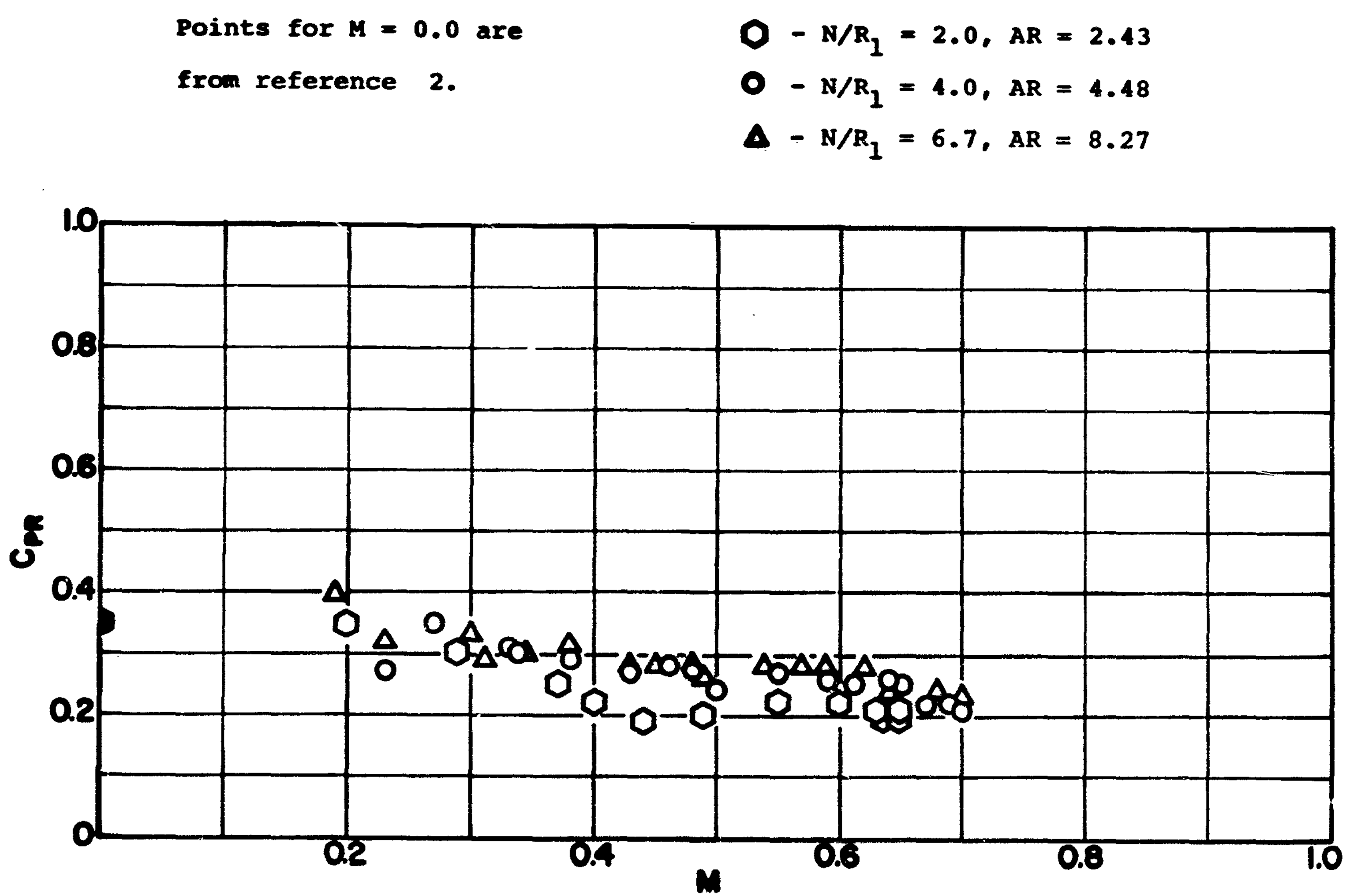

Figure 14. Diffuser Performance vs. Inlet Mach Number for $2\phi = 31.2^{o}$.

the water flow studies of McDonald and Fox[2]. The agreement with the present air flow studies for incompressible flow is excellent. A comparisc of Figures 15 and 16 shows that there is a slight upward shift in the location of the line $\alpha-\alpha$ as the inlet Mach number is increased from 0.25 to 0.55. However the shift is within the uncertainty in the data. When the inlet Mach number is increased to 0.70, line $\alpha-\alpha$ is slightly lower than that for $M_1 = 0.25$ (Compare Figures 15 and 17); again the shift is within the uncertainty in the data.

From the performance maps it can be seen that for a given inlet Mach number and diffuser area ratio, there is an optimum diffuser length which will result in maximum pressure recovery. This point is illustrated further in Figure 18. Figure 18 shows diffuser performance as a function of area ratic for various values of the length ratio and an inlet Mach number of 0.70. It can be seen that at low values of area ratio the curves coincide. As the area ratio increases, the curves for the lower values of length ratio drop off. From this plot, one can readily determine the optimum length ratio for maximum performance at a given area ratio. For example, for an area ratio = 1.70 and Mach number = 0.70, Figure 18 indicates that no increase in performance is to be gained by going to an N/R_1 above 8.0.

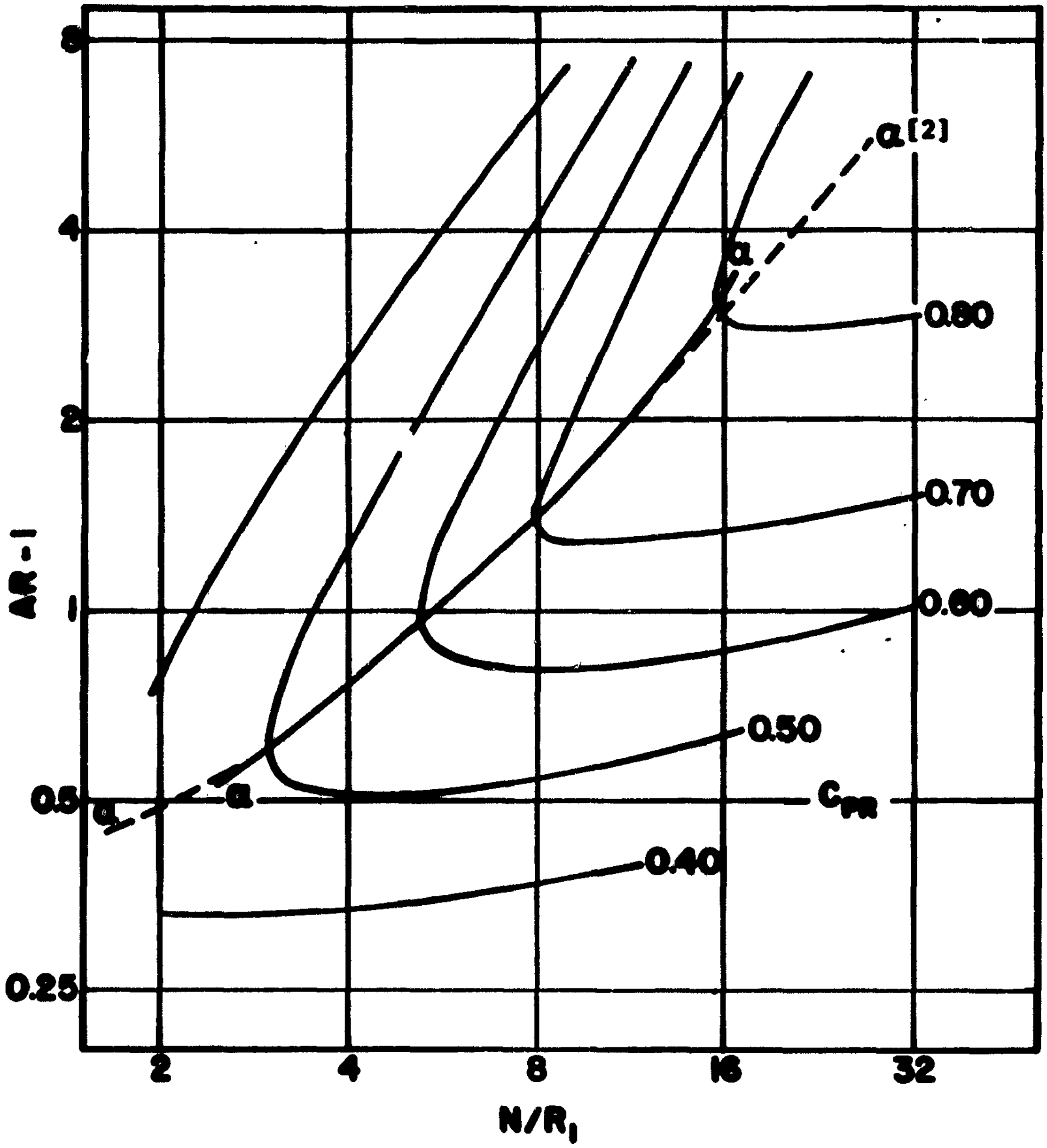

Figure 15. Performance Map for Conical Diffusers with M_1=0.25

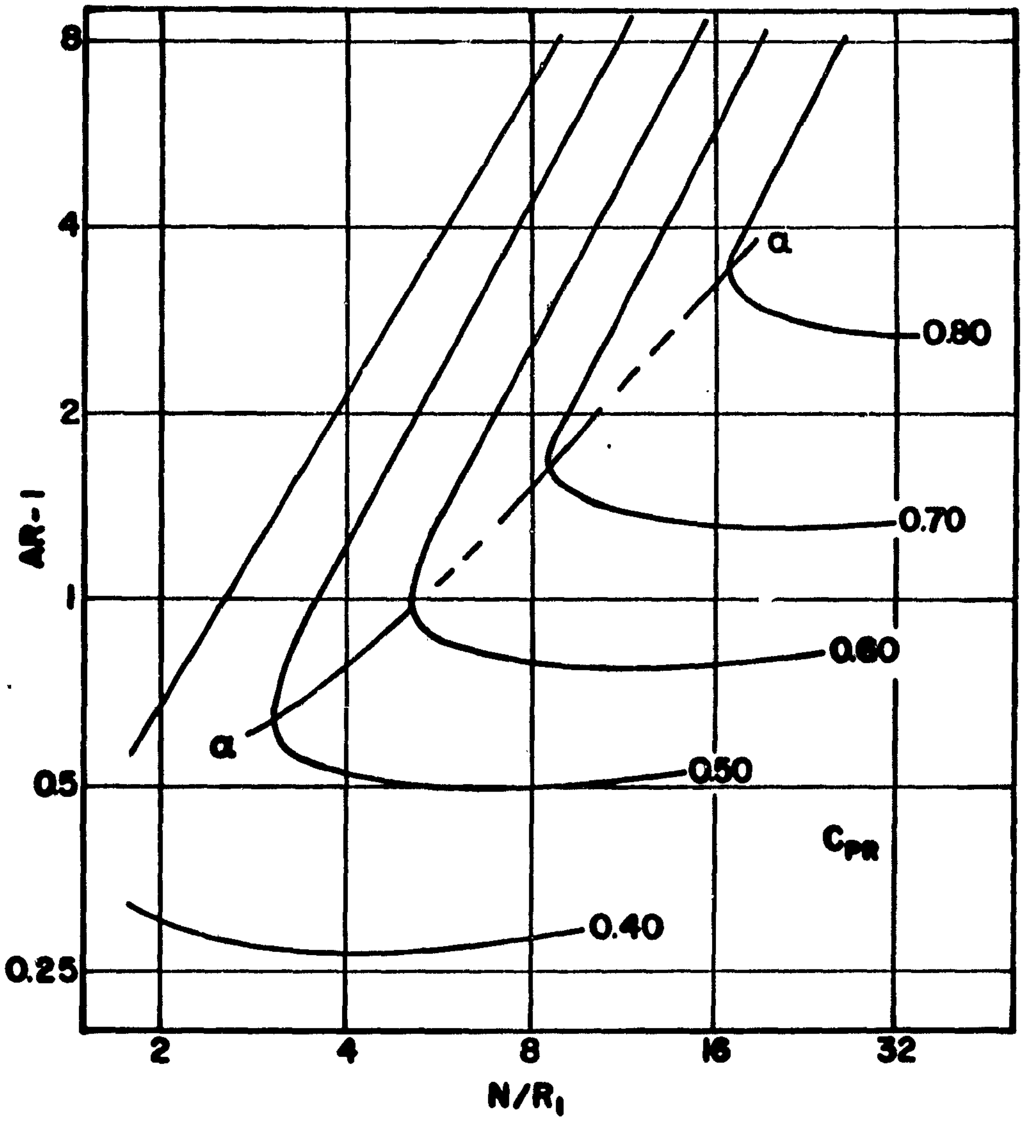

Figure 16. Performance Map for Conical Diffusers with M_1=0.55

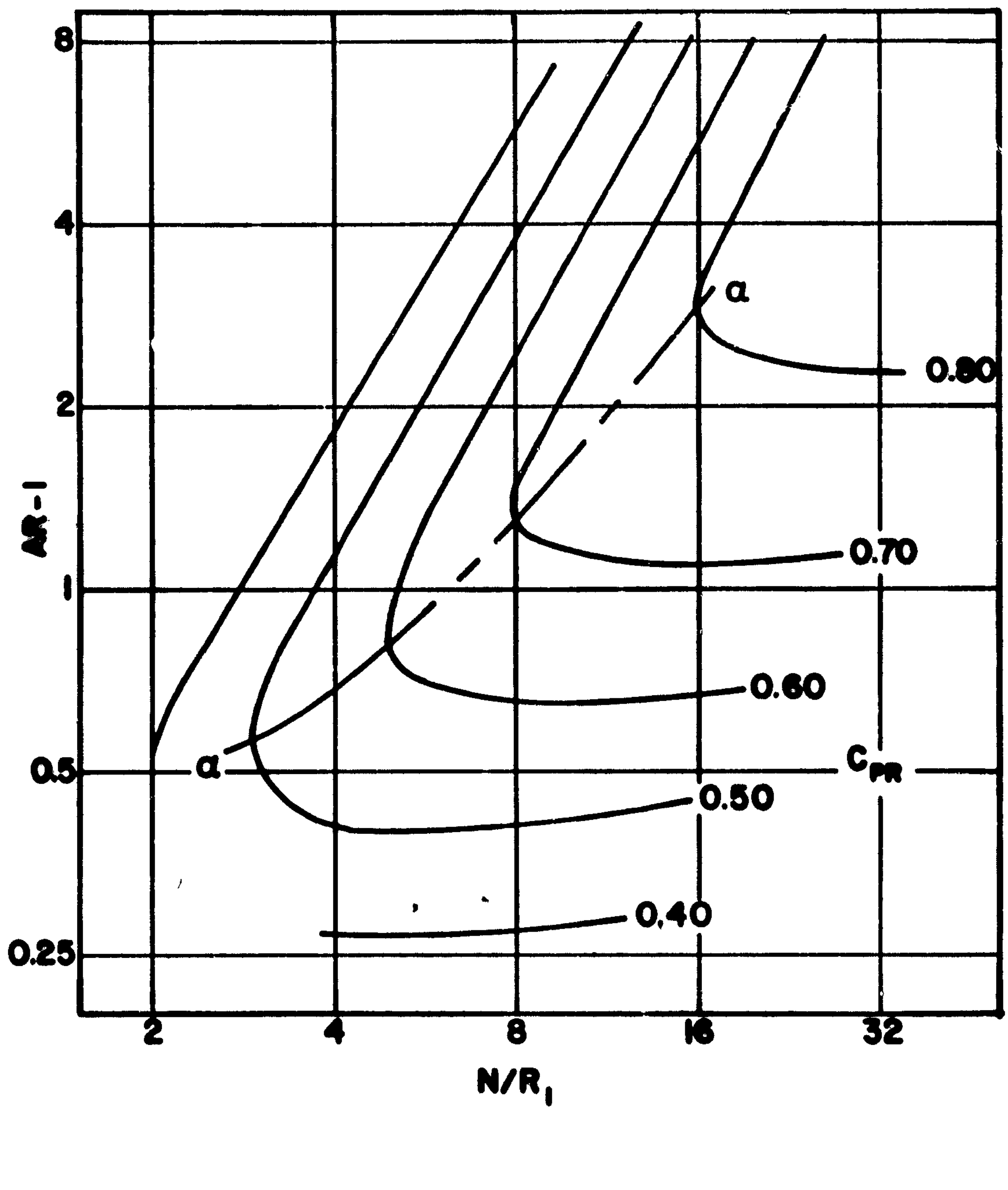

Figure 17. Performance Map for Conical Diffusers with M_1=0.70

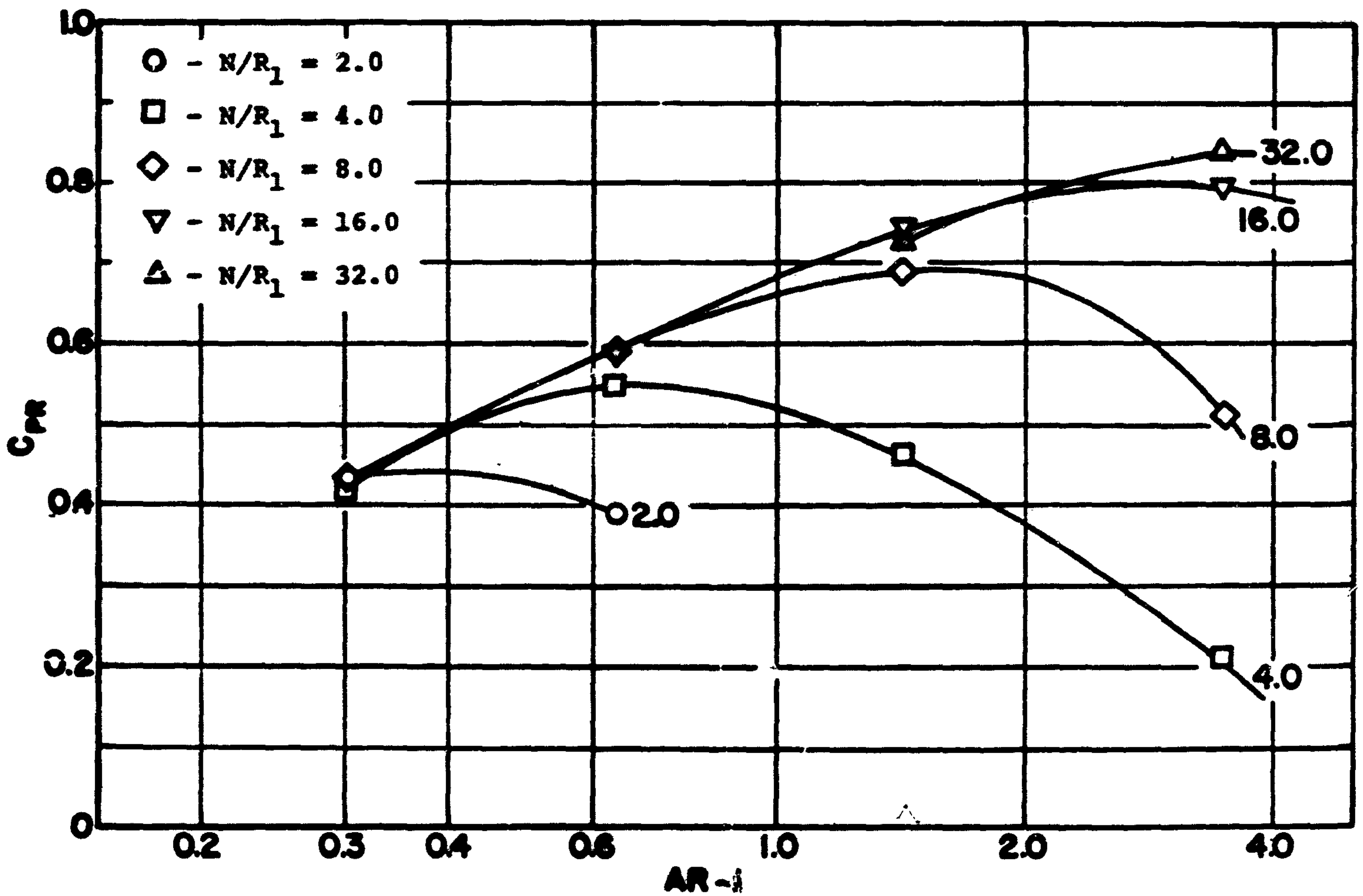

Figure 18. Diffuser Performance vs AR-1 for Constant N/R_1 at M_1 = 0.70

CONCLUSIONS

From a consideration of the foregoing experimental results, the following conclusions can be drawn:

1. For incompressible flow the line of first appreciable stall, line a-a, is essentially that found by McDonald and Fox[2]. As the Mach number is increased, however, the flow tends more toward separation in all cases.
2. The variation of the diffuser performance with inlet Mach number appears to correlate on the location of line a-a for incompressible flow.
   - For diffuser geometries lying below line a-a there is a slight increase in diffuser performance with increasing Mach number.
   - For diffuser geometries lying close to line a-a diffuser performance is essentially constant up to the point of local choking.
   - For diffuser geometries lying above the line a-a diffuser performance decreases with increasing Mach number.
3. At a given area ratio, diffuser performance, for a given Mach number, is independent of diffuser divergence angle (or length ratio) for diffuser geometries lying below the line of first appreciable stall. For a given area ratio, diffuser performance will drop off at all Mach numbers as one proceeds to geometries

lying above line a-a. The drop off in performance increases with increasing distance above the line a-a.

4. For a given divergence angle, diffuser performance at any Mach number is maximum for the maximum area ratio. The spread in performance as a function of area ratio for a given divergence angle decreases as the divergence angle is increased. At a divergence angle of 31.2 degrees, diffuser performance is uniformly low and independent of area ratio at all Mach numbers.

5. There is no significant variation in the location of the line of maximum performance at constant length to inlet radius ratio, line α-α, with inlet Mach number. For $M_1 = 0.25$ line α-α of the present study is virtually identical to that found in the earlier water flow studies of McDonald and Fox[2].

6. For a given area ratio and inlet Mach number there is an optimum length beyond which no increase in diffuser performance is obtained.

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APPENDIX A

Data and Calculated Performance Parameters for Current Investigation

Table A1. 2ϕ = 2.0 degrees N/R_1 = 8.0 AR = 1.30

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)				Diffuser	
	psf	$x10^{5}$	psi	psi	1.5	3.5	5.5	7.5	C_{PR}	η
0.25	88.	0.24	14.91	14.30	0.08	0.12	0.20	0.24	0.32	0.75
0.26	95.	0.25	14.98	14.32	0.07	0.11	0.15	0.19	0.26	0.61
0.30	134.	0.30	15.11	14.17	0.05	0.08	0.24	0.29	0.34	0.78
0.43	273.	0.42	15.74	13.83	0.05	0.12	0.21	0.28	0.35	0.79
0.53	405.	0.51	16.36	13.51	0.05	0.11	0.19	0.29	0.35	0.75
0.54	418.	0.52	16.38	13.44	0.05	0.13	0.21	0.30	0.36	0.78
0.62	537.	0.58	16.85	13.04	0.05	0.14	0.24	0.32	0.39	0.79
0.67	632.	0.63	17.19	12.70	0.06	0.16	0.25	0.34	0.41	0.83
0.70	682.	0.65	17.34	12.48	0.07	0.17	0.27	0.36	0.43	0.85
0.74	748.	0.68	17.51	12.16	0.08	0.19	0.29	0.38	0.45	0.87
0.76	778.	0.69	17.59	12.01	0.08	0.20	0.31	0.40	0.46	0.88
0.76	791.	0.70	17.86	12.18	0.07	0.17	0.26	0.35	0.42	0.80
0.79	847.	0.72	18.05	11.96	0.08	0.18	0.28	0.37	0.43	0.81
0.83	922.	0.74	18.32	11.67	0.08	0.19	0.29	0.38	0.44	0.80
0.85	963.	0.76	18.45	11.47	0.08	0.21	0.30	0.39	0.45	0.81

Table A2. 2ϕ = 2.0 degrees N/R_1 = 16.0 AR = 1.64

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)					Diffuser	
	psf	x10^5	psi	psi	1.5	3.5	5.5	7.5	11.5	C_{PR}	η
0.22	71.	0.21	14.76	14.27	0.05	0.15	0.15	0.25	0.35	0.50	0.79
0.30	134.	0.29	14.98	14.05	0.05	0.11	0.18	0.26	0.37	0.50	0.78
0.37	193.	0.35	15.18	13.83	0.05	0.11	0.20	0.27	0.40	0.51	0.78
0.41	242.	0.39	15.33	13.63	0.04	0.12	0.19	0.29	0.42	0.53	0.79
0.47	311.	0.44	15.55	13.36	0.05	0.11	0.20	0.30	0.44	0.53	0.80
0.53	387.	0.49	15.77	13.04	0.05	0.12	0.20	0.29	0.44	0.55	0.81
0.59	469.	0.54	16.01	12.70	0.05	0.13	0.21	0.30	0.45	0.56	0.81
0.67	597.	0.60	16.36	12.11	0.05	0.15	0.24	0.33	0.49	0.58	0.82
0.74	707.	0.64	16.63	11.57	0.07	0.17	0.26	0.35	0.50	0.60	0.83
0.81	818.	0.68	16.85	10.95	0.08	0.19	0.29	0.38	0.56	0.63	0.84
0.87	897.	0.69	16.70	10.19	0.06	0.23	0.34	0.44	0.60	0.69	0.91

Table A3. 2ϕ = 2.0 degrees N/R_1 = 32.0 AR = 2.43

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)									Diffuser	
	psf	$x10^5$	psi	psi	1.5	3.5	5.5	9.5	15.5	17.5	21.5	25.5	29.5	C_{PR}	η
0.22	67	0.21	14.66	14.20	0.05	0.11	0.16	0.32	0.47	0.53	0.79	0.65	0.67	0.68	0.82
0.33	151.	0.31	14.86	13.80	0.05	0.12	0.16	0.33	0.44	0.49	0.61	0.65	0.67	0.68	0.80
0.42	249.	0.39	15.06	13.31	0.04	0.11	0.18	0.36	0.47	0.53	0.61	0.64	0.67	0.70	0.82
0.53	380.	0.48	15.33	12.65	0.05	0.12	0.20	0.37	0.49	0.53	0.61	0.65	0.69	0.71	0.82
0.61	489.	0.54	15.52	12.06	0.04	0.14	0.22	0.39	0.51	0.56	0.63	0.67	0.70	0.72	0.82
0.69	603.	0.59	15.74	11.45	0.05	0.15	0.24	0.41	0.53	0.57	0.65	0.68	0.71	0.73	0.82
0.78	732.	0.63	15.97	10.71	0.06	0.17	0.27	0.44	0.56	0.60	0.66	0.70	0.73	0.75	0.82
0.84	825.	0.66	16.06	10.10	0.08	0.20	0.30	0.47	0.59	0.63	0.68	0.72	0.75	0.77	0.84
0.87	860.	0.67	16.16	9.92	0.08	0.21	0.31	0.48	0.60	0.63	0.69	0.72	0.75	0.77	0.83

Table A4. 2ϕ = 4.0 degrees N/R_1 = 4.0 AR = 1.30

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)		Diffuser	
	psf	x10^5	psi	psi	1.5	3.5	C_{PR}	η
0.21	67.	0.21	14.81	14.34	0.16	0.32	0.37	0.88
0.28	113.	0.27	15.01	14.22	0.16	0.31	0.38	0.87
0.35	176.	0.34	15.28	14.05	0.16	0.32	0.38	0.89
0.41	242.	0.40	15.57	13.88	0.15	0.32	0.38	0.86
0.47	312.	0.45	15.87	13.68	0.16	0.34	0.39	0.86
0.56	439.	0.53	16.38	13.29	0.17	0.35	0.40	0.86
0.61	527.	0.58	16.75	13.02	0.18	0.36	0.41	0.84
0.69	659.	0.64	17.27	12.58	0.18	0.37	0.42	0.85
0.75	761.	0.68	17.56	12.11	0.21	0.40	0.46	0.88
0.78	817.	0.70	17.71	11.84	0.23	0.42	0.47	0.89
0.81	866.	0.72	17.86	11.62	0.24	0.43	0.48	0.89

Table A5. $2\phi = 4.0$ degrees $W/R_1 = 8.0$ AR = 1.64

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)				Diffuser	
	psf	$\times 10^5$	psi	psi	1.5	3.5	5.5	7.5	C_{PR}	η
0.49	332	0.46	15.60	13.26	0.14	0.32	0.43	0.50	0.54	0.81
0.54	401	0.50	15.82	12.99	0.13	0.32	0.62	0.51	0.55	0.81
0.60	483	0.54	16.04	12.62	0.15	0.34	0.45	0.53	0.56	0.82
0.66	577	0.59	16.31	12.21	0.15	0.35	0.47	0.54	0.58	0.82
0.72	674	0.63	16.58	11.77	0.16	0.36	0.48	0.56	0.59	0.82
0.77	760	0.66	16.78	11.32	0.18	0.38	0.50	0.57	0.61	0.82
0.82	834	0.69	16.97	10.95	0.20	0.40	0.50	0.58	0.61	0.82
0.89	949	0.72	17.22	10.32	0.23	0.42	0.53	0.61	0.64	0.83
0.90	995	0.74	17.61	10.37	0.12	0.36	0.49	0.57	0.60	0.77
0.90	998	0.74	17.73	10.46	0.03	0.32	0.46	0.55	0.58	0.75
0.91	991	0.73	17.49	10.27	0.16	0.38	0.51	0.59	0.62	0.79

Table A6. $2\phi = 4.0$ degrees $N/R_1 = 16.0$ AR = 2.43

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)					Diffuser	
	psf	x10^5	psi	psi	1.5	3.5	5.5	7.5	11.5	C_{PR}	η
0.48	315	0.44	15.28	13.07	0.15	0.33	0.43	0.46	0.65	0.70	0.81
0.59	455	0.52	15.52	12.31	0.16	0.34	0.46	0.60	0.68	0.72	0.83
0.70	617	0.59	15.82	11.42	0.17	0.37	0.48	0.63	0.71	0.74	0.83
0.74	686	0.62	15.97	11.05	0.18	0.38	0.48	0.62	0.71	0.74	0.82
0.81	790	0.65	16.16	10.46	0.21	0.40	0.51	0.64	0.72	0.75	0.82
0.85	842	0.67	16.26	10.17	0.22	0.41	0.51	0.65	0.72	0.76	0.82
0.92	959	0.70	16.53	9.53	0.21	0.42	0.52	0.66	0.73	0.76	0.81
0.92	979	0.71	16.95	9.80	0.02	0.31	0.44	0.60	0.67	0.70	0.75
0.93	1001	0.72	17.05	9.73	0.05	0.31	0.45	0.59	0.67	0.70	0.75

Table A7. 2ϕ = 4.0 degrees N/R_1 = 32.0 AR = 4.48

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)									Diffuser	
	psf	$\times 10^5$	psi	psi	1.5	3.5	5.5	9.5	13.5	17.5	21.5	25.5	29.5	C_{PR}	η
0.26	95	0.25	14.66	14.00	0.15	0.33	0.45	0.56	0.71	0.82	0.78	0.82	0.82	0.85	0.89
0.35	169	0.33	14.76	13.58	0.15	0.34	0.42	0.59	0.67	0.73	0.80	0.82	0.82	0.84	0.87
0.45	273	0.41	14.91	12.99	0.16	0.34	0.43	0.58	0.66	0.72	0.79	0.82	0.82	0.83	0.86
0.56	407	0.49	15.08	12.21	0.16	0.36	0.45	0.60	0.69	0.74	0.79	0.82	0.82	0.83	0.86
0.68	569	0.56	15.28	11.22	0.18	0.38	0.48	0.63	0.71	0.76	0.81	0.83	0.84	0.84	0.86
0 76	688	0.61	15.47	10.54	0.20	0.40	0.49	0.64	0.71	0.76	0.80	0.82	0.83	0.84	0.85
0.89	865	0.65	15.72	9.43	0.23	0.43	0.53	0.66	0.73	0.78	0.82	0.84	0.85	0.85	0.84
0.90	897	0.67	15.92	9.38	0.17	0.39	0.50	0.64	0.71	0.76	0.80	0.82	0.82	0.83	0.82
0.91	920	0.68	16.24	9.53	0.07	0.33	0.45	0.60	0.67	0.71	0.75	0.77	0.78	0.79	0.78

Table A8. 2ϕ = 8.0 degrees W/R_1 = 2.0 AR = 1.30

M_1	q_1	Re_{D_1}	P_o	P_1	C_{PR} X(in)	Diffuser	
	psf	x10^5	psi	psi	1.5	C_{PR}	η
0.21	67.	0.21	14.86	14.39	0.32	0.37	0.88
0.29	127.	0.29	15.11	14.22	0.31	0.39	0.89
0.36	190.	0.35	15.40	14.07	0.32	0.39	0.91
0.42	260.	0.41	15.72	13.90	0.31	0.38	0.86
0.47	322.	0.46	15.97	13.71	0.32	0.38	0.85
0.52	391.	0.50	16.26	13.51	0.37	0.40	0.86
0.57	459.	0.54	16.53	13.29	0.34	0.40	0.84
0.61	534.	0.58	16.85	13.07	0.34	0.40	0.83
0.65	602.	0.62	17.10	12.82	0.36	0.42	0.85
0.69	665.	0.64	17.34	12.60	0.37	0.43	0.85
0.72	709.	0.66	17.49	12.43	0.38	0.43	0.86
0.74	755.	0.68	17.66	12.26	0.39	0.44	0.85

Table A9. $2\phi = 8.0$ degrees $W/R_1 = 4.0$ AR = 1.64

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)		Diffuser	
	psf	x10^5	psi	psi	1.5	3.5	C_{PR}	η
0.21	67	0.21	14.79	14.32	0.32	0.47	0.58	0.92
0.28	116	0.28	14.98	14.17	0.30	0.46	0.52	0.80
0.34	165	0.33	15.15	14.00	0.32	0.47	0.51	0.79
0.38	204	0.36	15.28	13.85	0.31	0.49	0.52	0.79
0.42	256	0.41	15.45	13.66	0.32	0.48	0.52	0.78
0.46	305	0.44	15.60	13.46	0.33	0.49	0.53	0.80
0.52	384	0.49	15.87	13.17	0.32	0.50	0.53	0.79
0.59	476	0.54	16.14	12.77	0.34	0.51	0.54	0.79
0.63	547	0.58	16.38	12.50	0.35	0.51	0.54	0.78
0.69	641	0.62	16.70	12.13	0.36	0.52	0.55	0.77
0.74	717	0.65	16.92	11.79	0.36	0.53	0.56	0.77
0.80	822	0.69	17.24	11.32	0.38	0.54	0.57	0.76
0.81	828	0.68	17.00	11.03	0.42	0.58	0.61	0.82
0.82	848	0.70	17.29	11.18	0.39	0.54	0.56	0.77
0.85	916	0.72	17.51	10.88	0.40	0.55	0.58	0.76
0.88	957	0.73	17.66	10.71	0.40	0.55	0.58	0.76
0.89	977	0.74	17.78	10.68	0.38	0.54	0.57	0.74

Table A10. 2ϕ = 8.0 degrees N/R_1 = 8.0 AR = 2.43

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)				Diffuser	
	psf	x10^5	psi	psi	1.5	3.5	5.5	7.5	C_{PR}	η
0.22	71	0.21	14.71	14.22	0.30	0.50	0.55	0.65	0.70	0.84
0.30	127	0.29	14.84	13.95	0.31	0.47	0.61	0.67	0.70	0.83
0.36	183	0.34	14.98	13.71	0.31	0.48	0.59	0.65	0.68	0.80
0.43	256	0.40	15.13	13.34	0.33	0.50	0.62	0.67	0.69	0.81
0.51	353	0.47	15.35	12.87	0.33	0.50	0.61	0.67	0.69	0.80
0.57	438	0.51	15.55	12.45	0.34	0.50	0.61	0.69	0.69	0.80
0.64	530	0.56	15.77	12.01	0.35	0.51	0.61	0.67	0.69	0.79
0.71	647	0.61	16.06	11.45	0.36	0.51	0.61	0.68	0.69	0.77
0.78	749	0.65	16.33	10.95	0.37	0.51	0.61	0.68	0.69	0.76
0.83	840	0.67	16.58	10.51	0.38	0.52	0.62	0.68	0.69	0.76
0.88	923	0.70	16.83	10.12	0.38	0.51	0.61	0.67	0.69	0.75
0.90	992	0.74	17.61	10.39	0.19	0.37	0.51	0.58	0.61	0.65
0.90	995	0.74	17.78	10.54	0.12	0.33	0.48	0.56	0.58	0.63
0.90	996	0.75	17.86	10.61	0.10	0.31	0.47	0.55	0.57	0.62
0.91	967	0.72	17.07	10.02	0.36	0.49	0.60	0.66	0.68	0.73
0.91	987	0.73	17.34	10.14	0.30	0.44	0.56	0.63	0.64	0.69

Table A11. 2ϕ = 8.0 degrees W/R_1 = 16.0 AR = 4.48

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)					Diffuser	
	psf	x10^5	psi	psi	1.5	3.5	5.5	7.5	11.5	C_{PR}	η
0.23	78	0.22	14.66	14.12	0.32	0.50	0.64	0.68	0.77	0.82	0.86
0.34	162	0.32	14.81	13.68	0.31	0.48	0.61	0.68	0.74	0.79	0.82
0.42	246	0.39	14.93	13.21	0.33	0.49	0.58	0.65	0.72	0.79	0.82
0.52	363	0.47	15.13	12.58	0.34	0.50	0.59	0.66	0.73	0.79	0.81
0.64	526	0.55	15.40	11.67	0.36	0.50	0.61	0.68	0.75	0.79	0.81
0.71	620	0.59	15.60	11.18	0.37	0.51	0.61	0.67	0.74	0.79	0.80
0.79	745	0.63	15.87	10.51	0.38	0.51	0.61	0.67	0.74	0.78	0.78
0.85	838	0.66	16.09	10.02	0.38	0.51	0.61	0.67	0.73	0.78	0.77
0.91	927	0.69	16.41	9.65	0.36	0.49	0.59	0.65	0.72	0.76	0.75
0.91	953	0.70	16.73	9.78	0.29	0.43	0.54	0.60	0.67	0.72	0.71
0.91	964	0.71	16.95	9.92	0.22	0.37	0.50	0.57	0.64	0.69	0.68
0.91	977	0.72	17.19	10.07	0.11	0.30	0.45	0.53	0.62	0.66	0.65

Table A12. 2ϕ = 8.0 degrees N/R_1 = 26.8 AR = 8.27

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)									Diffuser	
	psf	x10^5	psi	psi	1.5	3.5	5.5	7.5	11.5	15.5	19.5	23.5	27.5	C_{PR}	η
0.26	99	0.25	14.66	13.98	0.32	0.50	0.61	0.68	0.79	0.82	0.86	0.86	0.86	0.86	0.87
0.35	169	0.33	14.76	13.58	0.34	0.50	0.61	0.67	0.75	0.80	0.83	0.84	0.84	0.84	0.84
0.43	256	0.40	14.86	13.07	0.36	0.50	0.61	0.68	0.75	0.79	0.83	0.84	0.84	0.84	0.85
0.50	332	0.45	14.98	12.65	0.34	0.49	0.60	0.67	0.75	0.79	0.82	0.83	0.83	0.83	0.83
0.56	404	0.49	15.08	12.23	0.36	0.50	0.60	0.67	0.74	0.79	0.82	0.83	0.83	0.83	0.83
0.62	485	0.53	15.20	11.77	0.36	0.50	0.61	0.68	0.74	0.79	0.82	0.83	0.83	0.83	0.82
0.68	579	0.57	15.35	11.22	0.37	0.51	0.61	0.67	0.74	0.78	0.82	0.83	0.83	0.83	0.82
0.79	734	0.62	15.67	10.39	0.39	0.51	0.60	0.67	0.74	0.77	0.81	0.82	0.82	0.82	0.80
0.79	734	0.62	15.67	10.39	0.39	0.51	0.60	0.67	0.74	0.77	0.80	0.81	0.82	0.82	0.80
0.86	841	0.65	15.89	9.80	0.40	0.51	0.61	0.67	0.74	0.77	0.80	0.81	0.82	0.82	0.79
0.91	924	0.68	16.28	9.55	0.34	0.46	0.57	0.63	0.70	0.74	0.75	0.77	0.78	0.78	0.75
0.91	960	0.71	16.87	9.87	0.17	0.33	0.47	0.55	0.62	0.66	0.69	0.70	0.70	0.70	0.68
0.91	984	0.73	17.39	10.22	0.03	0.22	0.38	0.46	0.55	0.59	0.62	0.63	0.64	0.64	0.61

Table A13. 2ϕ = 15.8 degrees W/R_1 = 2.0 AR = 1.64

M_1	q_1	Re_{D_1}	P_o	P_1	C_{PR} X(in)	Diffuser	
	psf	x10^5	psi	psi	1.5	C_{PR}	η
0.22	67	0.33	14.74	14.27	0.37	0.47	0.83
0.31	137	0.47	15.03	14.07	0.39	0.44	0.72
0.38	207	0.58	15.35	13.90	0.36	0.41	0.65
0.42	256	0.65	15.57	13.78	0.36	0.40	0.62
0.47	315	0.71	15.84	13.63	0.35	0.39	0.61
0.52	391	0.79	16.14	13.39	0.36	0.41	0.62
0.58	469	0.87	16.53	13.21	0.35	0.39	0.58
0.62	537	0.93	16.83	13.02	0.36	0.39	0.58
0.68	645	0.10	17.29	12.70	0.36	0.39	0.57
0.72	712	0.11	17.61	12.53	0.36	0.39	0.56
0.74	752	0.11	17.81	12.43	0.36	0.39	0.55

Table A14. 2ϕ = 15.8 degrees N/R_1 = 4.0 AR = 2.43

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)		Diffuser	
	psf	$\times 10^5$	psi	psi	1.5	3.5	C_{PR}	η
0.26	95	0.25	14.86	14.20	0.33	0.45	0.48	0.58
0.31	141	0.30	15.01	14.02	0.35	0.48	0.50	0.60
0.38	211	0.37	15.30	13.83	0.34	0.44	0.47	0.56
0.43	263	0.41	15.47	13.63	0.34	0.44	0.48	0.57
0.47	318	0.45	15.70	13.46	0.33	0.43	0.48	0.56
0.54	404	0.51	16.01	13.17	0.3[illegible]	0.45	0.48	0.55
0.59	486	0.55	16.36	12.92	0.33	0.44	0.47	0.54
0.64	571	0.60	16.73	12.67	0.33	0.42	0.46	0.53
0.69	658	0.64	17.12	12.43	0.31	0.41	0.46	0.51
0.74	745	0.67	17.46	12.13	0.32	0.42	0.46	0.51
0.77	791	0.69	17.64	11.96	0.28	0.41	0.47	0.51
0.78	820	0.70	17.81	11.91	0.26	0.41	0.46	0.50
0.78	824	0.71	17.86	11.94	0.24	0.40	0.45	0.50

Table A15. 2ϕ = 15.8 degrees W/R_1 = 8.0 AR = 4.48

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)				Diffuser	
	psf	x10^5	psi	psi	1.5	3.5	5.5	7.5	C_{PR}	η
0.25	88	0.24	14.84	14.22	0.28	0.40	0.44	0.48	0.52	0.55
0.40	225	0.38	15.25	13.68	0.31	0.41	0.47	0.52	0.55	0.57
0.45	291	0.43	15.47	13.44	0.33	0.40	0.47	0.51	0.55	0.57
0.53	387	0.49	15.84	13.12	0.31	0.38	0.45	0.49	0.53	0.55
0.68	631	0.62	16.75	12.26	0.30	0.37	0.44	0.49	0.52	0.53
0.73	716	0.66	17.17	12.05	0.29	0.35	0.42	0.47	0.50	0.51
0.77	784	0.69	17.46	11.84	0.28	0.35	0.42	0.47	0.50	0.50
0.79	833	0.70	17.68	11.69	0.28	0.35	0.41	0.46	0.49	0.49
0.81	869	0.72	17.83	11.57	0.26	0.34	0.41	0.46	0.49	0.49
0.82	885	0.72	17.93	11.54	0.25	0.32	0.40	0.46	0.49	0.49
0.83	918	0.74	18.13	11.50	0.24	0.32	0.39	0.44	0.48	0.48
0.84	931	0.74	18.13	11.40	0.24	0.32	0.48	0.53	0.49	0.48

Table A16. 2ϕ = 15.8 degrees W/R_1 = 13.4 AR = 8.27

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)					Diffuser	
	psf	$x10^5$	psi	psi	1.5	3.5	7.5	9.5	13.5	C_{PR}	η
0.22	71	0.21	14.79	14.30	0.35	0.45	0.60	0.60	0.60	0.60	0.61
0.29	120	0.28	14.93	14.10	0.32	0.44	0.56	0.59	0.59	0.59	0.60
0.37	197	0.36	15.18	13.80	0.32	0.41	0.50	0.56	0.56	0.57	0.58
0.46	294	0.43	15.45	13.39	0.32	0.42	0.49	0.55	0.57	0.59	0.59
0.54	404	0.50	15.82	12.97	0.32	0.40	0.47	0.53	0.55	0.58	0.58
0.65	567	0.59	16.38	12.35	0.32	0.39	0.46	0.52	0.54	0.57	0.56
0.71	674	0.64	16.80	11.99	0.30	0.37	0.45	0.51	0.53	0.56	0.55
0.77	783	0.68	17.27	11.64	0.29	0.36	0.43	0.50	0.52	0.54	0.53
0.83	894	0.72	17.66	11.20	0.28	0.35	0.43	0.50	0.52	0.55	0.53
0.86	949	0.74	17.95	11.08	0.25	0.33	0.41	0.48	0.51	0.53	0.52

Table A17. 2ϕ = 31.2 degrees N/R_1 = 2.0 AR = 2.43

M_1	q_1	Re_{D_1}	P_o	P_1	C_{PR} X(in)	Diffuser	
	psf	x10^5	psi	psi	1.5	C_{PR}	η
0.20	60	0.32	14.91	14.49	0.29	0.35	0.42
0.29	120	0.45	15.23	14.39	0.24	0.30	0.35
0.34	165	0.53	15.45	14.30	0.15	0.30	0.35
0.37	200	0.58	15.67	14.27	-0.04	0.25	0.31
0.40	242	0.64	15.94	14.25	0.04	0.22	0.27
0.44	284	0.69	16.24	14.25	0.04	0.19	0.23
0.49	360	0.78	16.65	14.12	0.12	0.20	0.24
0.55	453	0.87	17.12	13.93	0.18	0.22	0.26
0.60	538	0.95	17.61	13.80	0.18	0.22	0.25
0.63	592	1.00	17.95	13.75	0.16	0.21	0.24
0.64	609	1.00	18.08	13.75	0.16	0.20	0.24
0.65	626	1.00	18.15	13.71	0.16	0.20	0.24
0.65	636	1.00	18.20	13.68	0.16	0.21	0.24

Table A18. $2\phi = 31.2$ degrees $N/R_1 = 4.0$ $AR = 4.48$

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)		Diffuser	
	psf	$x10^5$	psi	psi	1.5	3.5	C_{PR}	η
0.23	78	0.23	14.86	14.32	0.23	0.27	0.27	0.33
0.27	102	0.26	14.96	14.25	0.24	0.28	0.35	0.36
0.33	162	0.33	15.28	14.15	0.24	0.26	0.31	0.32
0.38	207	0.37	15.52	14.07	0.22	0.24	0.29	0.30
0.43	273	0.42	15.89	13.98	0.19	0.22	0.27	0.28
0.46	305	0.45	16.04	13.90	0.19	0.21	0.28	0.29
0.48	332	0.47	16.21	13.88	0.15	0.17	0.27	0.28
0.50	363	0.49	16.43	13.88	0.12	0.15	0.24	0.25
0.55	436	0.53	16.75	13.68	0.15	0.19	0.27	0.28
0.55	449	0.55	16.92	13.75	0.13	0.17	0.23	0.24
0.59	500	0.57	17.10	13.56	0.17	0.20	0.26	0.28
0.61	548	0.60	17.39	13.51	0.16	0.19	0.25	0.26
0.64	595	0.63	17.64	13.41	0.17	0.20	0.26	0.27
0.64	599	0.63	17.81	13.56	0.14	0.18	0.21	0.23
0.65	626	0.64	17.83	13.39	0.05	0.20	0.25	0.26
0.67	666	0.66	18.15	13.41	0.14	0.18	0.22	0.24
0.69	707	0.69	18.42	13.39	0.14	0.17	0.22	0.23
0.70	727	0.70	18.54	13.36	0.14	0.18	0.21	0.23

Table A19. 2ϕ = 31.2 degrees N/R_1 = 6.7 AR = 8.27

M_1	q_1	Re_{D_1}	P_o	P_1	Local C_{PR} X(in)			Diffuser	
	psf	$\times 10^5$	psi	psi	1.5	3.5	5.5	C_{PR}	η
0.19	53	0.19	14.71	14.34	0.27	0.33	0.33	0.40	0.41
0.23	78	0.23	14.86	14.32	0.23	0.27	0.27	0.32	0.32
0.30	127	0.29	15.08	14.20	0.25	0.28	0.31	0.33	0.34
0.31	144	0.31	15.20	14.20	0.22	0.24	0.24	0.29	0.30
0.34	165	0.33	15.30	14.15	0.24	0.26	0.26	0.30	0.30
0.38	207	0.37	15.50	14.05	0.22	0.24	0.27	0.31	0.31
0.43	267	0.42	15.84	13.98	0.27	0.21	0.23	0.28	0.28
0.45	294	0.44	15.99	13.93	0.20	0.22	0.23	0.28	0.28
0.48	336	0.47	16.19	13.83	0.20	0.21	0.24	0.28	0.28
0.49	356	0.48	16.36	13.85	0.16	0.19	0.23	0.26	0.26
0.54	418	0.52	16.63	13.68	0.19	0.21	0.25	0.28	0.28
0.57	473	0.56	16.92	13.58	0.19	0.20	0.24	0.28	0.28
0.59	514	0.58	17.14	13.51	0.19	0.20	0.24	0.28	0.27
0.62	551	0.60	17.32	13.41	0.19	0.21	0.25	0.28	0.28
0.62	568	0.61	17.46	13.44	0.18	0.19	0.22	0.27	0.27
0.64	609	0.63	17.81	13.48	0.14	0.16	0.21	0.24	0.24
0.68	683	0.67	18.23	13.36	0.14	0.16	0.21	0.24	0.23
0.70	713	0.69	18.45	13.36	0.13	0.15	0.20	0.23	0.22
0.70	730	0.70	18.52	13.31	0.14	0.16	0.20	0.23	0.23

APPENDIX F

Tabulation of Diffuser Performance at Selected Mach Numbers and Cross Plots of Data Used in Plotting Performance Maps

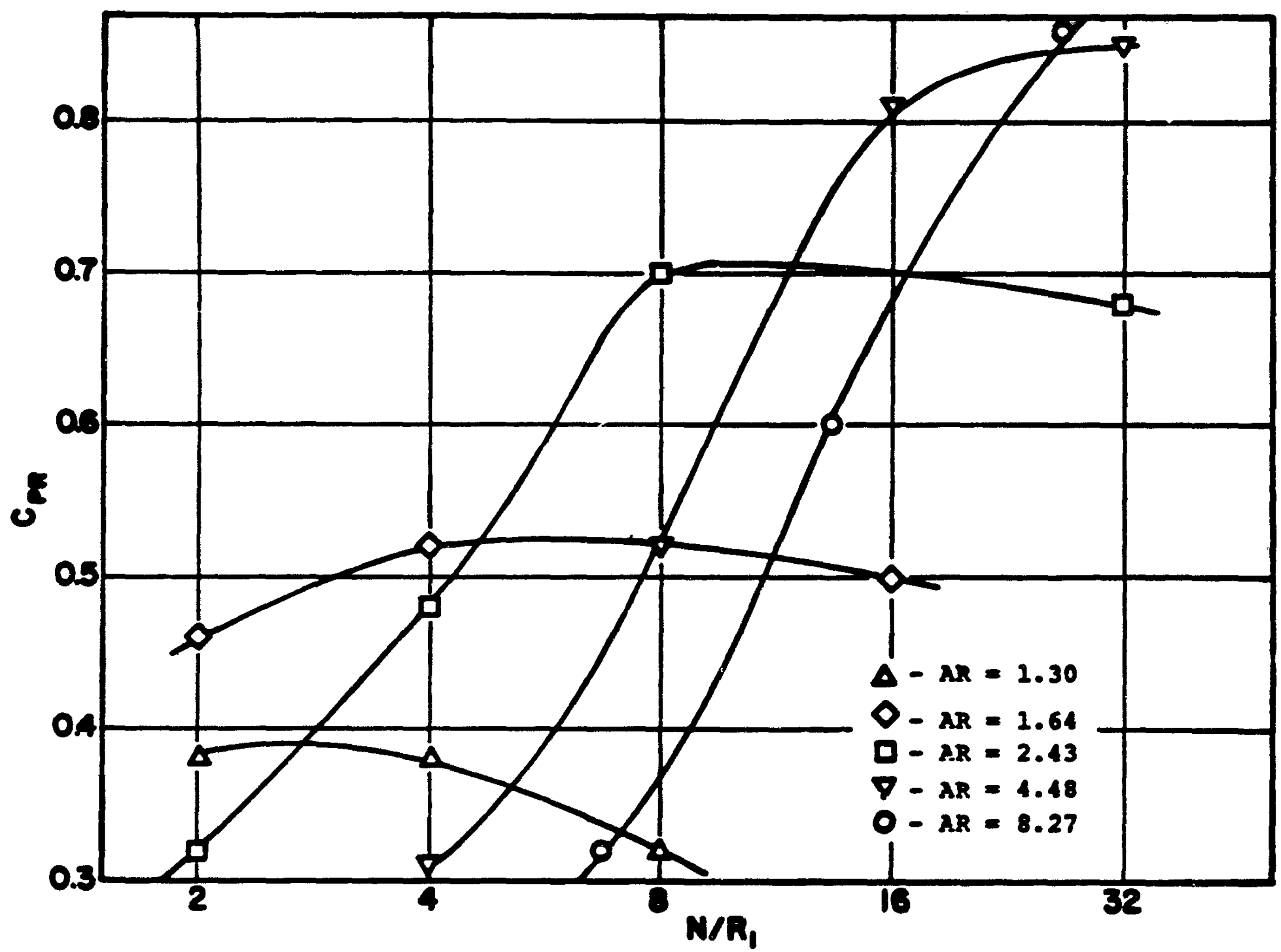

Figure B1. C_{PR} vs N/R_1 at Constant AR for M_1 = 0.25

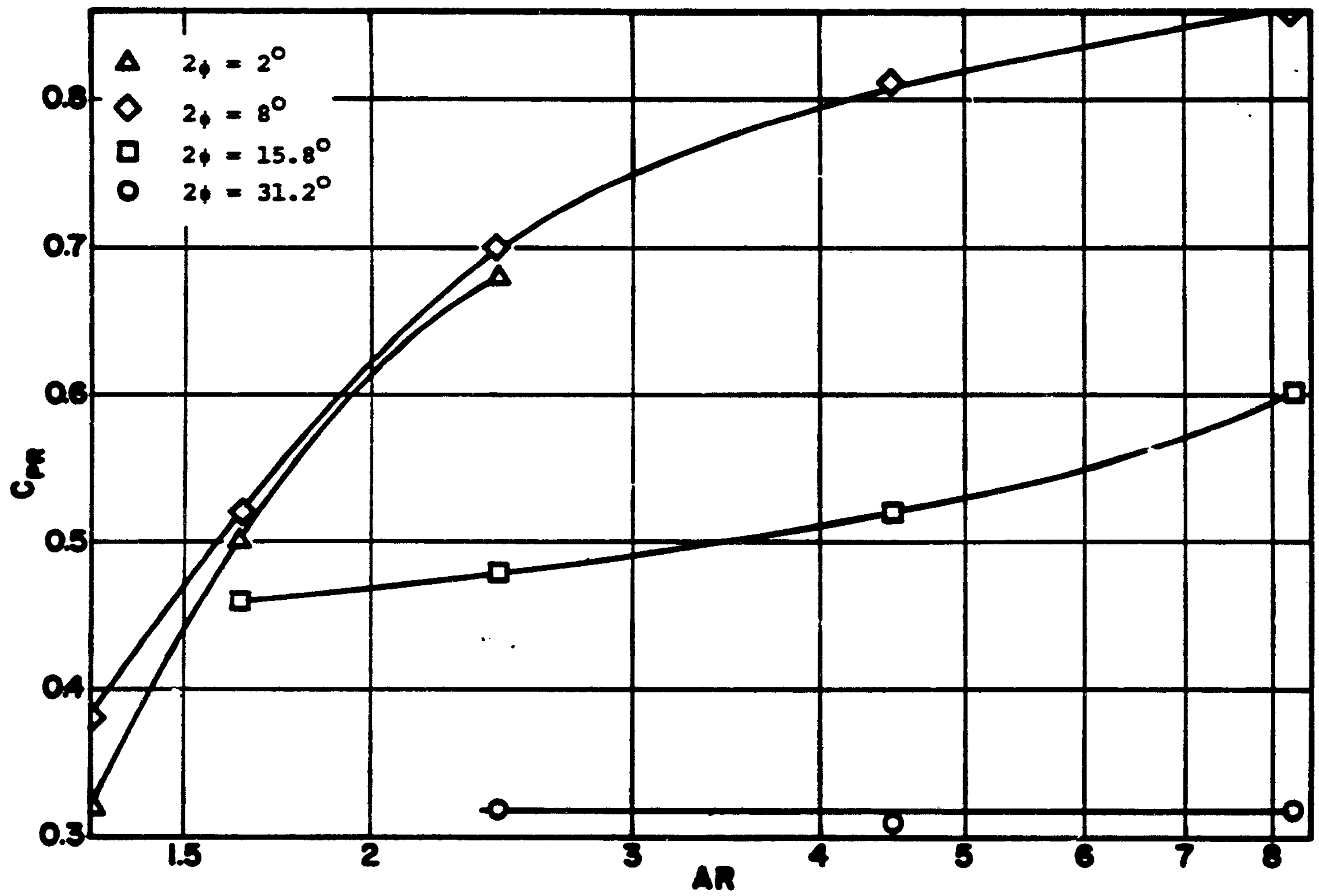

Figure B2. C_{PR} vs AR at Constant 2ϕ for $M_1 = 0.25$

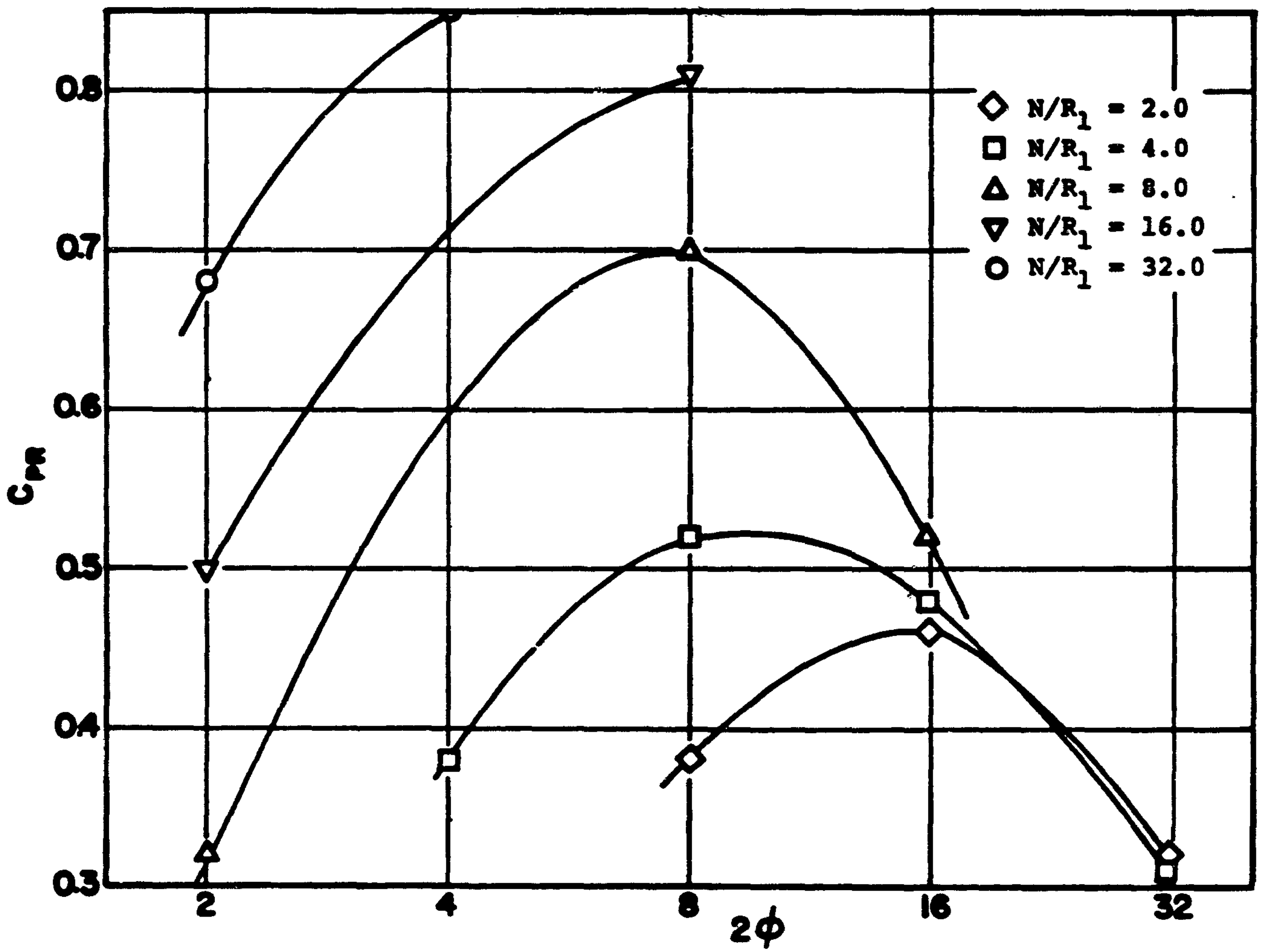

Figure B3. C_{PR} vs 2ϕ at Constant N/R_1 for M_1 = 0.25

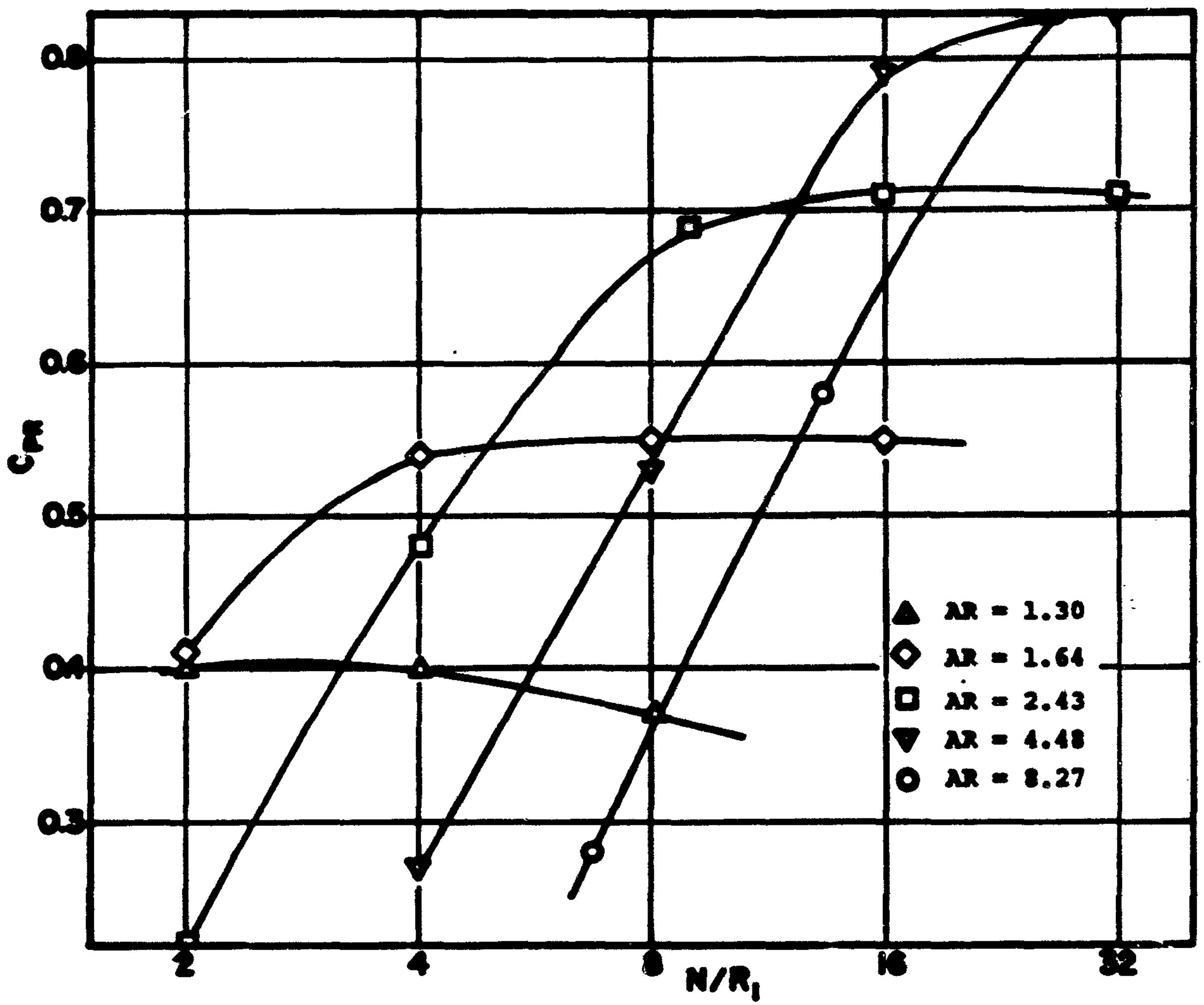

Figure B4. C_{PR} vs N/R_1 at Constant AR for M_1 = 0.55

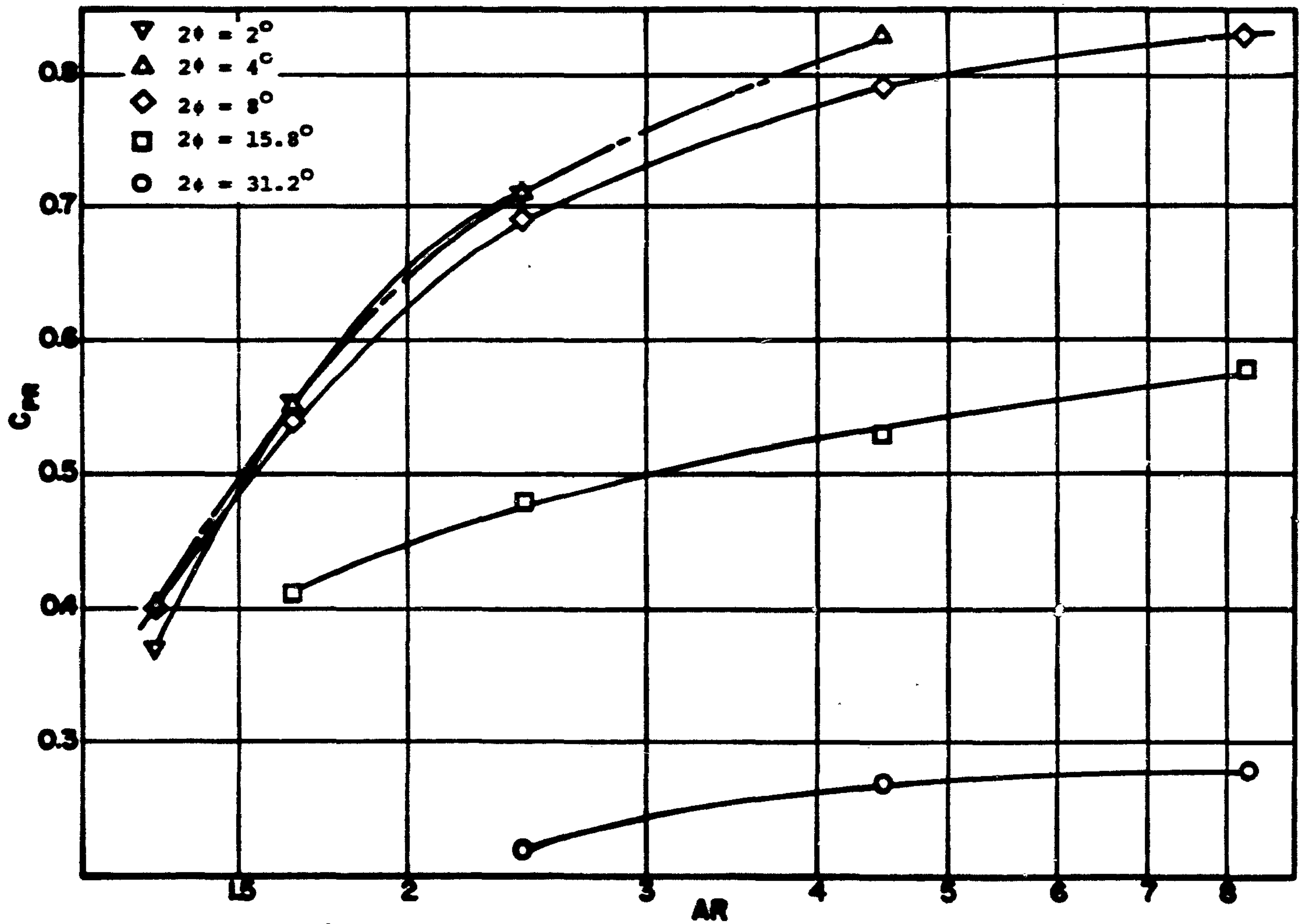

Figure B5. C_{PR} vs AR at Constant 2ϕ for $M_1 = 0.55$

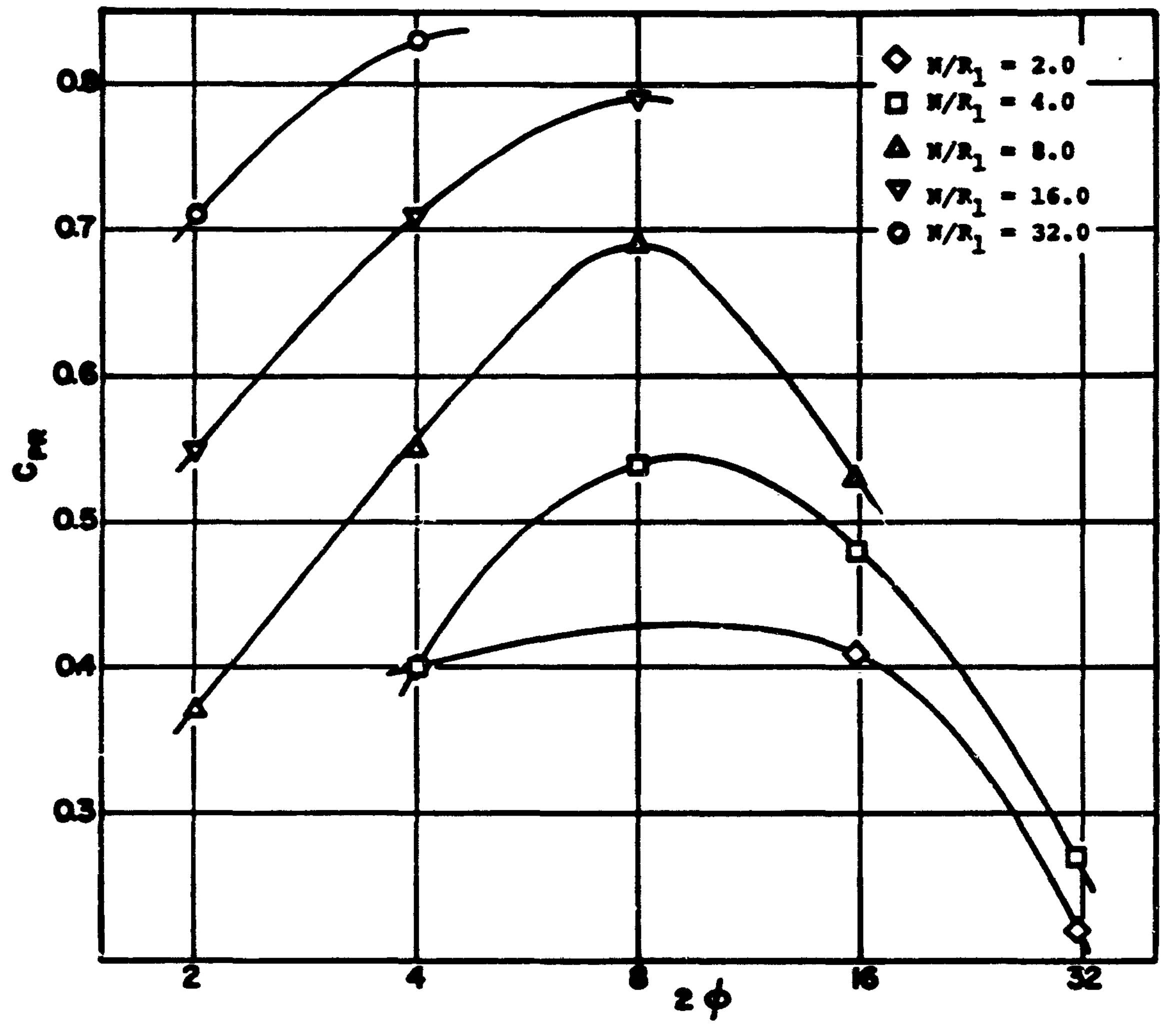

Figure B6. C_{PR} vs 2ϕ at Constant N/R_1 for $M_1 = 0.55$

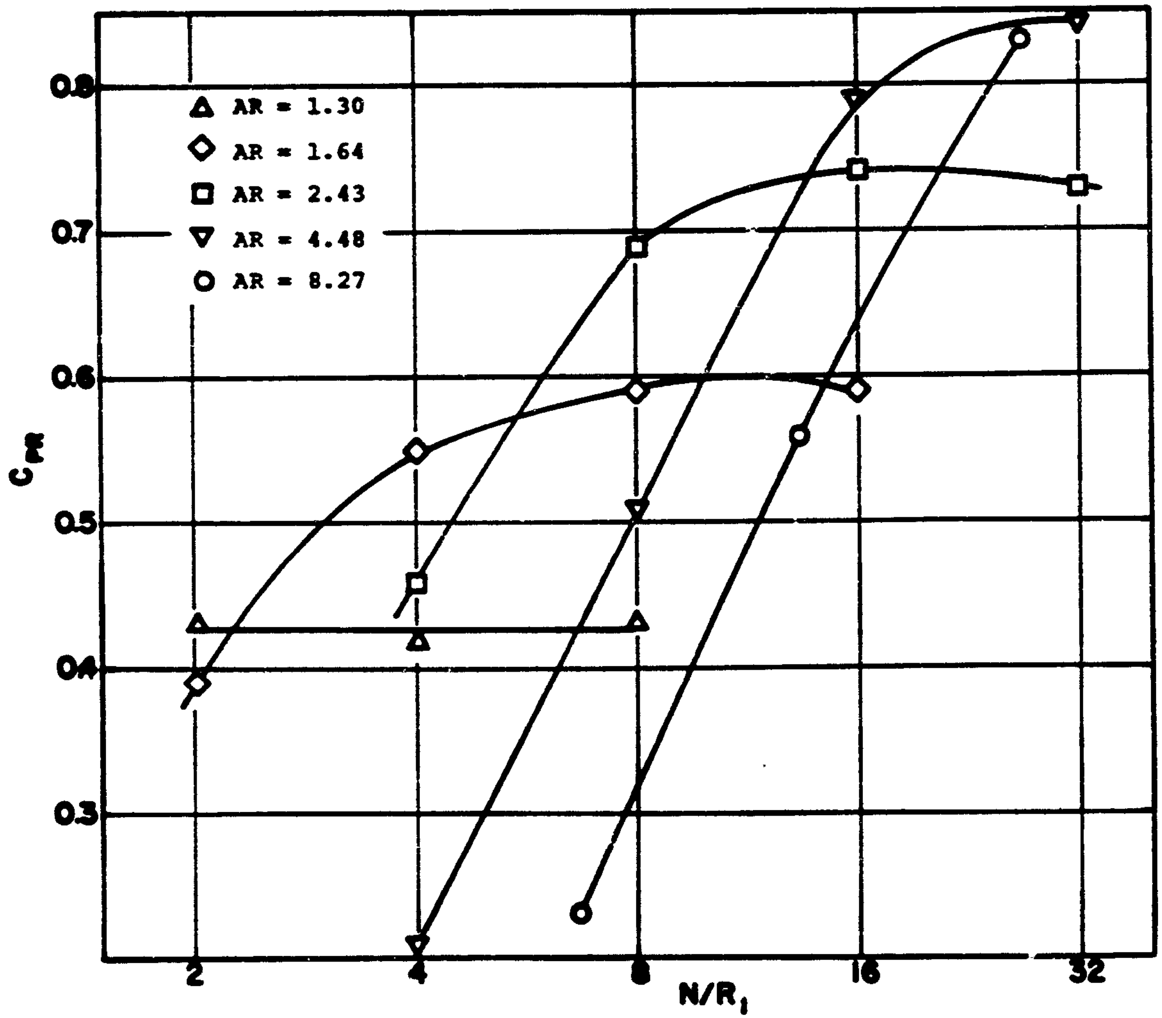

Figure B7. C_{PR} vs N/R_1 at Constant AR for M_1 = 0.70

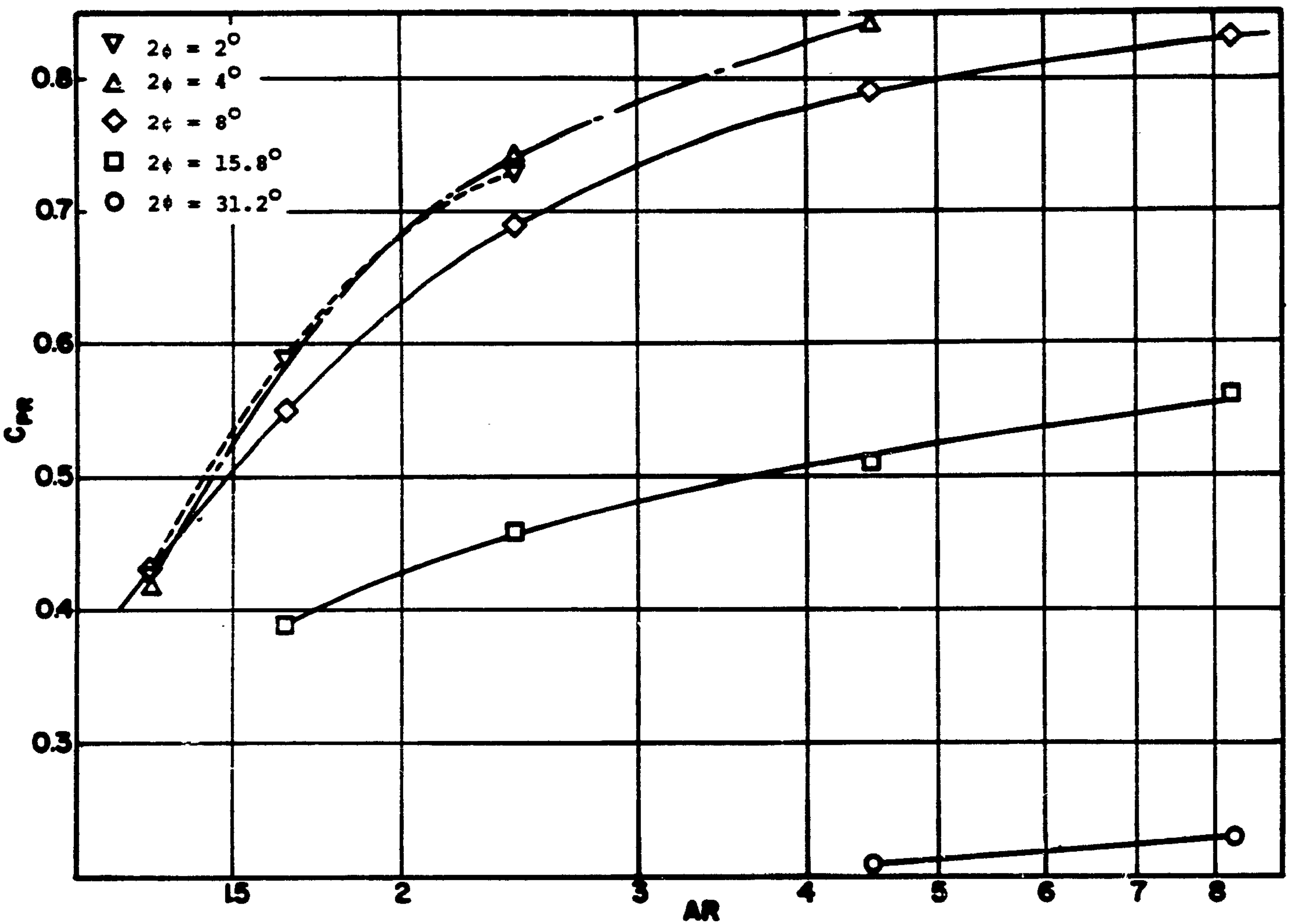

Figure B8. C_{PR} vs AR at Constant 2ϕ for $M_1 = 0.70$

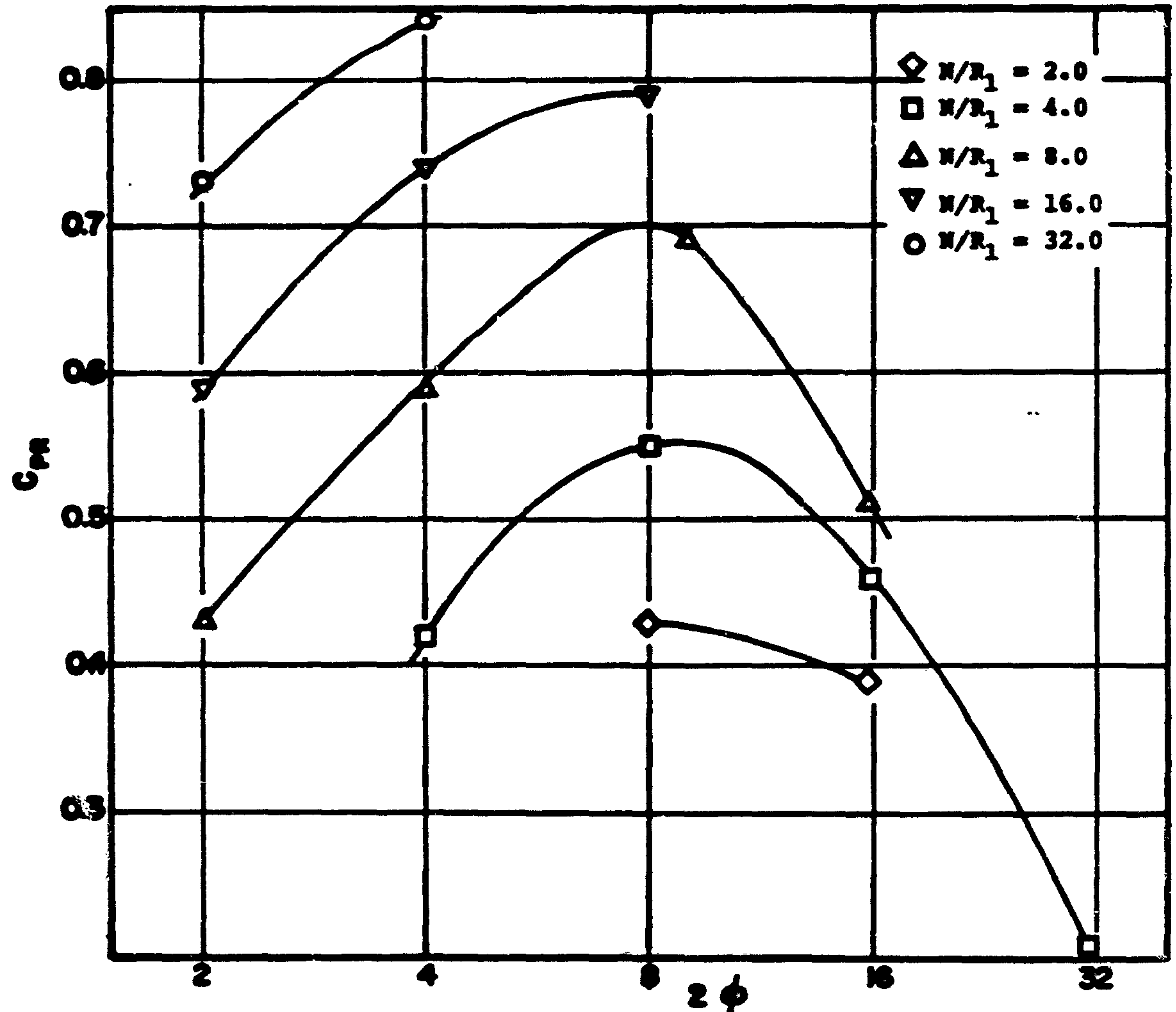

Figure B9. C_{PR} vs 2ϕ at Constant N/R_1 for M_1 = 0.70

Table B.1 Diffuser Performance at Selected Mach Numbers. Tabulated data taken from plots of C_{PR} vs M.

2θ degrees	N/R_1	AR	C_{PR} $M_1 = 0.25$	$M_1 = 0.55$	$M_1 = 0.70$
2.0	8.0	1.30	.32	.37	.43
2.0	16.0	1.64	.50	.55	.59
2.0	32.0	2.43	.68	.71	.73
4.0	4.0	1.30	.38	.40	.42
4.0	8.0	1.64		.55	.59
4.0	16.0	2.43		.71	.74
4.0	32.0	4.48	.85	.83	.84
8.0	2.0	1.30	.38	.40	.43
8.0	4.0	1.64	.52	.54	.55
8.0	8.0	2.43	.70	.69	.69
8.0	16.0	4.48	.81	.79	.79
8.0	26.8	8.27	.86	.83	.83
15.8	2.0	1.64	.46	.41	.39
15.8	4.0	2.43	.48	.48	.46
15.8	8.0	4.48	.52	.53	.51
15.8	13.4	8.27	.60	.58	.56
31.2	2.0	2.43	.32	.22	
31.2	4.0	4.48	.31	.27	.21
31.2	6.7	8.27	.32	.28	.23

APPENDIX C. Method of Obtaining Performance Maps

The diffuser performance maps (contours of constant C_{PR} on coordinates of AR-1 vs N/R_1) of Figures 16, 17, and 18 have been drawn from the cross-plots given in Appendix B; the data used in the cross-plots is tabulated in Tables B·1.

For a given inlet Mach number the data of Table B·1 has been plotted as C_{PR} vs 2ϕ at constant N/R_1. (For $M_1 = 0.25$ these plots are shown in Figure B1, B2 and B3 respectively.) From each of these plots one can then obtain a series of diffuser geometries which will yield a given value of C_{PR}. Consider the case of $M_1 = 0.25$; suppose further that we are interested in obtaining diffuser geometries for which $C_{PR} = 0.5$. From Figure B1 we see that there are five conical diffuser geometries for which we would expect $C_{PR} = 0.5$; from Figure B2 we obtain three additional geometries; Figure B3 yields another five geometries. Thus the contour of $C_{PR} = 0.5$ on the performance map of Figure 15 is based on a total of thirteen points.

By following this procedure sufficient points were obtained to enable smooth contours of constant C_{PR} to be established on the performance maps.

APPENDIX D. Discussion of Diffuser Choking

The results of the present study indicate that for a given inlet Mach number, diffuser performance may be multi-valued, i.e. there may be a value of the inlet Mach number for which the slope of the C_{PR} vs M_1 curve becomes infinite. This is not surprising. In fact it can be shown that theoretically this occurs for an inlet Mach number of unity.

The diffuser performance is given by

$$C_{PR} = \frac{P_2 - P_1}{\frac{1}{2}\rho_1 U_1^2} = \frac{(\frac{P_2}{P_1} - 1)}{\frac{1}{2}\frac{\rho_1}{P_1} U_1^2}$$

Treating air as an ideal gas, then $P_1 = \rho_1 R T_1$, and the sonic velocity is given by $c_1 = \sqrt{kRT_1}$

Thus we can write

$$C_{PR} = \frac{(\frac{P_2}{P_1} - 1)}{\frac{kM_1^2}{2}}$$

where k is the specific heat ratio (k=1.4 for air).

In the present study the diffuser is preceded by a converging section (fig. 3); the flow from the diffuser discharges to the atmosphere. Thus for a given diffuser there is a wide range of upstream stagnation pressures which will give a throat Mach number of unity. Since, P_2 = constant, then with $M_1 = 1$, the diffuser inlet pressure, P_1, can be increased arbitrarily by increasing the upstream stagnation pressure; thus the slope of the C_{PR} vs M_1 curve becomes infinite at a value of $M_1 = 1$.

The data indicate that this sudden sharp decrease in diffuser performance occurred at a measured inlet Mach number less than unity (but greater than $M_1 = 0.90$). This may be expected if one considers the location of the inlet pressure tap. For ease of construction the inlet pressure tap (for measurement of P_1) was located in the straight section of the inlet nozzle a distance of 1.12 inches upstream of the diffuser throat. If one considers the flow between the pressure tap and the diffuser throat as Fanno line flow, small frictional effects will cause relatively large increases in the Mach number for a measured Mach number $M_1 \geq 0.90$. That the throat velocity is sonic for $M_1 \geq 0.90$ can also be demonstrated from consideration of the one-dimensional isentropic flow tables. For $M_1 = 0.90$, $A_1/A^* = 1.0088$ where A^* is the flow area at which the Mach number is unity. Thus a very small increase in the boundary layer displacement thickness between the measuring station and the diffuser throat is sufficient to give a throat Mach number of unity.

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13. ABSTRACT

Experiments have been performed to determine the effect of subsonic inlet Mach number on diffuser performance and flow regimes for a wide range of conical diffuser geometries. For incompressible flow the line of first appreciable stall is essentially that found by McDonald and Fox. As the Mach number is increased, the flow tends more toward separation in all cases. Diffuser performance maps are presented for three different inlet Mach numbers (M_1 = 0.25, 0.55, 0.70). There is no significant variation in the location of the line of maximum performance at constant length to inlet radius ratio with inlet Mach number.

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Conical Diffusers						
Incompressible Flow						
Compressible Flow						
Flow Regimes						

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There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.